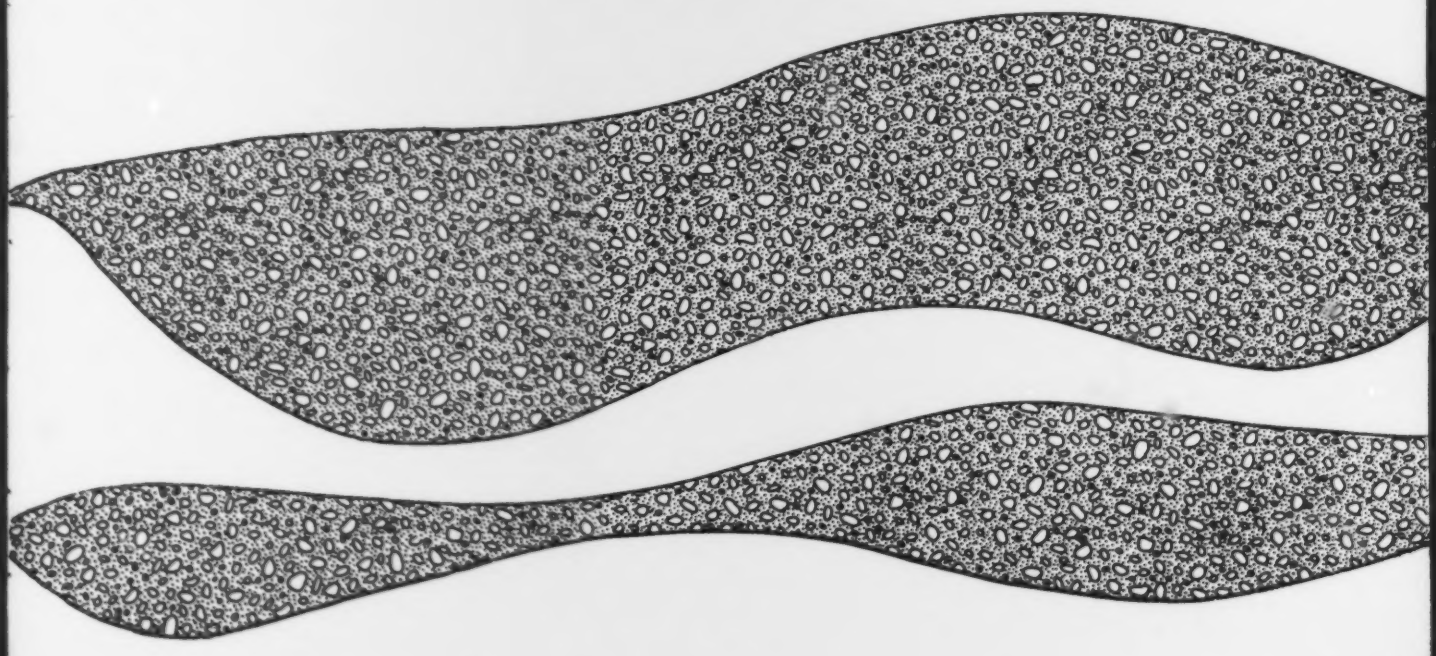
EVALUATING SALINE WATERS IN A PLAINS ENVIRONMENT

Edited by Don T. Waite



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FOREWORD

In June, 1982, the Second International Symposium on Athalassic (Inland) Saline Lakes was held at Emma Lake, Saskatchewan, Canada. Papers presented at the conference covered topics of biology, chemistry and geology. Outside of the formal sessions there was much talk of the need to preserve saline lakes and wetlands. There was, however, little information available at the meeting which would allow a manager to evaluate saline areas in terms of economic and ecological worth.

The purpose of the present symposium was to answer the question "What is a saline lake or wetland worth?" Six specialists were asked to evaluate recreational, industrial, agricultural, fisheries and wildlife aspects of prairie saline waters and to place these waters into a global context. The six authors are recognized for their long association with and study of prairie aquatic ecosystems. We hope that their experience will help those involved in the impact assessment process, wetland managers and others with an interest in plains saline waters to better appreciate the intrinsic value of these systems.

Many people helped in organizing the 1985 Plains Aquatic Research Conference, at which this symposium was presented. I would especially like to thank Mrs. L. Nelson and Ms. J. Stadnyk of the Canadian Plains Research Center for their assistance. The preparation of this publication could not have been done without Ms. Gillian Wadsworth Minifie, my co-editor from the C.P.R.C., and Mr. Brian Mlazgar, who input the material. My wife Anne helped with the difficult task of proofreading the manuscript. This symposium was jointly sponsored by Environment Canada, the Water Studies Research Institute and the Canadian Plains Research Center, University of Regina.

Don T. Waite
Editor
Regina, Saskatchewan
February 1986

SALINE LAKES: THEIR DISTRIBUTION AND CHARACTERISTICS

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ABSTRACT

Saline lakes occur in dry climatic regions in endorheic drainage basins the world over. They display a broad range of salinities from 3 to over 400 g/L salt. Evaporative concentration leads to the precipitation of minerals in order of solubilities. Although there is a broad spectrum of ion dominance, specific ions tend to dominate regionally depending on the source and proportions of salts in inflowing waters.

Saline lakes have most often been classified in various ways from the chemical point of view. No system accurately expresses tolerance and abundance for all biotic species since species are very diverse in their response to salinity. There is a drastic decline in the hyposaline range from maximal species numbers in non-saline waters to a steady decline of species numbers with increasing salinity through the mesosaline and hypersaline categories. Although some species are cosmopolitan, many others show regional distributions and only some show distinct chemical affinities.

INTRODUCTION

Saline lakes are common landscape features on every continent. They are frequently the only surface waters in large dry climatic regions. The largest permanent saline lakes are found in the Soviet Union including the Caspian Sea (436,400 km^2), the Sea of Aral (62,000 km^2), Lake Balkhash (17,300 km^2) and Issyk Kul (6,200 km^2) while the Great Salt Lake in the United States (4,350 km^2) and Lake Urmia (6,000 km^2) in Iran are some of the larger saline lakes elsewhere. Some saline lakes are also very deep including Issyk Kul, Balkhash and the Dead Sea (between Israel and Jordan) with mean depths of 320, 210 and 145 m respectively. Large shallow playa lakes such as Lake Eyre (up to 8,800 km^2 in Lake Eyre North) in Australia contain water only intermittently. The largest permanent saline lakes in other geographic regions are Qinghai Hu in China ((4,635 km^2), Lake Poopo in Peru (2,600 km^2), Lake Chilwa in Malawi, Africa (1,400 km^2), Big Quill Lake

in Canada (307 km^2), Lake Corangamite in Australia (233 km^2) and Lake El'ton (U.S.S.R.) in Europe (172 km^2). Most saline lakes, however, are small and shallow and may be ephemeral. The volume of saline lake water, 104,000 cubic kilometres, is almost as great as the volume of the world's fresh waters (125,000 km^3) (Vallentyne 1972).

Most of the original saline lake studies were conducted to ascertain their possibilities as mineral sources and the early investigators tended to be geologists. These studies took place on all continents except Antarctica. Biological studies were initiated by Daday in Hungary, Florentin in Lorraine, Butschinsky in Russia and Thienemann and Schmidt in Germany when they examined interesting animals in inland saline habitats in the late nineteenth and early twentieth centuries. Eventually this early work resulted in intensive studies in Germany during the 1920s and 1930s. During the same period studies were initiated in the United States and Canada particularly in California, Nevada, Utah, North Dakota and Saskatchewan. Surveys of the biota and chemistry of lakes in North, East and South Africa and India were also carried out during this time. A great deal of research has been conducted on African saline lakes, particularly in Egypt, East Africa and Chad, beginning in the late 1950s and 1960s and continuing to the present. Much research on Iranian saline lakes was carried out during the 1950s and 1960s and continues to the present. Some Turkish lakes were also investigated. The Dead Sea, once thought to be barren of life, has been extensively studied for more than two decades. Much research on saline alkaline lakes of Austria and Hungary and the saline lakes of Spain has been carried on for more than four decades. A resurgence of interest occurred in Canada and the United States during the 1960s and 1970s. Research on South American saline lakes has, until recently, been spasmodic and usually confined to rather narrow specialities. Australian saline lake studies really began in the 1960s and have been prominent ever since. Considerable attention has been paid to saline lakes in Antarctica beginning in the 1960s. Studies of saline lakes in Central China and Tibet have also been conducted over the same period and are continuing. A Saline Lake Institute has been established at Xining in Qinghai Province. A number of saline lake ecosystem studies have been conducted in the Soviet Union, particularly during the 1970s.

In the 1970s, the trend was to study the trophic dynamics of saline lakes. Primary productivity and, to a limited degree, secondary productivity of many of these ecosystems were studied. Part of the secondary production studies involved investigations of life cycles of little known saline organisms. Although early studies seemed to indicate that saline lakes were extremely productive, it soon became apparent that they covered the whole range of productivity. All trophic levels were examined in some studies but, as much manpower is required to carry out a complete ecosystem study, few have been done.

Geologists have continued to study saline lakes and their sediments. Theories concerning the chemical evolution of closed lakes have been elucidated by scientists such as Hardie, Jones and Eugster.

The renewed interest with regard to inland saline lake research is demonstrated by the initiation of a symposium series. The first was held in Australia in 1979 and the second in Saskatchewan in 1982. A third was held in Kenya in late August 1985. Other, more local, symposia in this subject have been and are being held.

Saline lakes have long been used as a source of minerals including common salt, sodium borate, sodium sulphate, sodium carbonate and gypsum. Many more minerals are present and will eventually be harvested. Saline lakes are used extensively for commercial fisheries, particularly in Asia and Africa. Recreational uses, including sport fishing, hunting, bathing and sailing, have probably developed to the greatest extent in North America. Saline lakes have long been used as health spas, particularly in eastern Europe and Asia, but Little Manitou Lake, Saskatchewan, has been used for the same functions in the past. Some use may be made agriculturally of lower salinity waters. The heat stored in lenses in certain meromictic heliothermic lakes has been the subject of considerable interest recently.

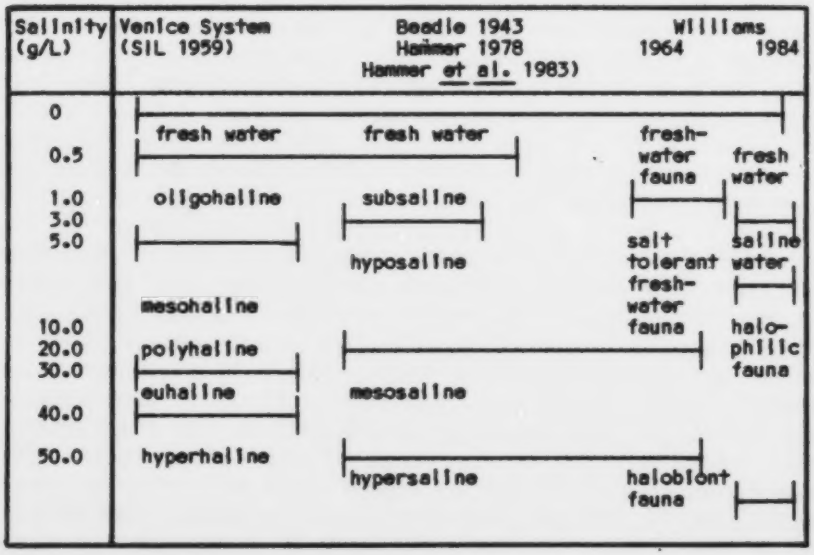
WHAT ARE SALINE LAKES?

For a considerable period, inland saline lakes were regarded essentially as extensions of marine waters and any less saline water was referred to as "brackish." Many arguments went on as to how to classify them but these were almost strictly on the basis of salinities and cut right across all types of water. In 1958 a Symposium in Venice established a classification system (Table 1) which avoided the use of the term "brackish" and substituted mixohaline for diluted sea water (SIL 1959). Beadle (1959) argued that inland saline lakes were a separate category which had little in common with marine or diluted sea water. Beadle, Bayly, and others, finally established that inland lakes tended to be inhabited by fauna which were of freshwater or terrestrial origin rather than marine origin.

The question of what constitutes saline lake water has long been debated. Many different systems have been used. In Saskatchewan Rawson & Moore (1944) adopted 300 mg/L salt to separate saline water from fresh water. Other systems including the Venice System used 500 mg/L while Loffler (1961) proposed 1000 mg/L as the lower level based on zooplankton distribution. Williams (1964) defined saline lakes as having a minimum of 3 g/L salt content and this has been well accepted as an arbitrary division point. He termed lakes less than 3 g/L fresh waters. Beadle (1943) had earlier, on ecological grounds, proposed three salinity categories based on animal distribution. These were up

to 20, 20-50 and from 50 g/L salt to near saturation. I have more or less adopted a combination of these schemes (Table 1). Fresh water has been designated at less than 500 mg/L (North American freshwater species are most abundant in this range), the subsaline transition ranges from 500-3000 mg/L, hyposaline from 3-20 g/L, mesosaline from 20-50 g/L and hypersaline above 50 g/L salt. This is a fairly arbitrary system roughly based on ecology of flora (Hammer et al. 1983) and fauna. The suffix 'saline' has been used instead of 'haline' so that any anion salt dominance (chloride, sulphate or carbonate) may be accommodated. Others (Williams 1981 in Table 1, and other Australian investigators) have developed more complex classification systems to account for a greater variety of species tolerances. It is probably more important to consider salinity ranges where species are abundant rather than using tolerance limits per se.

TABLE 1: Classification Systems for Saline Waters



Bayly (1967) proposed the term 'athalassic' (GK.: a, not; thalassic, sea) to describe inland waters which are associated with the land "irrespective of their salinity or position relative to the coastline, which have not been joined to the sea during geologically Recent times." This would include former marine sites which have been evaporated to dryness and then refilled from precipitation or runoff (but not from the sea) and repopulated. The kinds of salts present would be irrelevant. Excluded would be the Caspian Sea and the Sea of Aral which according to most authors have not been completely dry since they were part of a larger sea.

Salinity is a summation of the inorganic chemical constituents measured directly by chemical analyses. Total dissolved solids (total filtrable residue) is one measure of salinity which has been widely used. A sample of filtered lake water is evaporated to dryness at 105°C or 180°C. Dissolved organic matter may make up a considerable fraction of the total. Density is a similar parameter. Electrical conductivity may be determined directly in the field and is a measure of the ionized constituents present but does not include inorganic compounds. All of these parameters tend to correlate highly although the correlation is lower above 50 g/L total salts.

WHY AND WHERE DO SALINE LAKES OCCUR?

Certain climatic and geologic conditions are necessary for their existence. Since accumulation of salts is characteristic of saline lakes, special conditions are required to make this possible. These include evaporation exceeding precipitation, endorheic (internal) drainage basins in which lake basins occur and the availability of soluble salts.

Evaporation typically exceeds precipitation in hyperarid, arid, semiarid and subhumid regions of the world. The more arid regions are not good candidates for saline lakes because water tends to be ephemeral on the surface as in the world's great deserts. Temperature is an important associated parameter and is usually taken into consideration in establishing the location of the previously named climatic regions. Deeper lakes tend to be permanent even when they occur in hot deserts, e.g. the Dead Sea, Pyramid Lake in Nevada, but they usually receive runoff from less arid regions. Generally, many saline lakes occur in subhumid regions while the fewest lakes are present in the more arid zones. Antarctica differs from other continents since the prevailing temperatures are always low, lakes are often permanently ice-covered and meromictic and lose water through sublimation of ice rather than through evaporation.

Figure 1 illustrates the relationship between precipitation, evaporation and temperature with respect to some saline lakes. Net evaporation is the excess of evaporation over precipitation. It increases with higher mean annual temperatures. When evaporation exceeds precipitation, endorheic drainage basins result. Major endorheic drainage basins in prairie Canada are illustrated in Figure 2. Smaller regions are located in south-western Manitoba, in southern Saskatchewan and Alberta and in the Southern Interior Plateau in British Columbia. Endorheism is a requirement for the occurrence of saline lakes since it permits the retention of water in lake basins without continuous washout of salts, as occurs in freshwater lakes which overflow continuously or even intermittently (e.g., on the Canadian Shield).

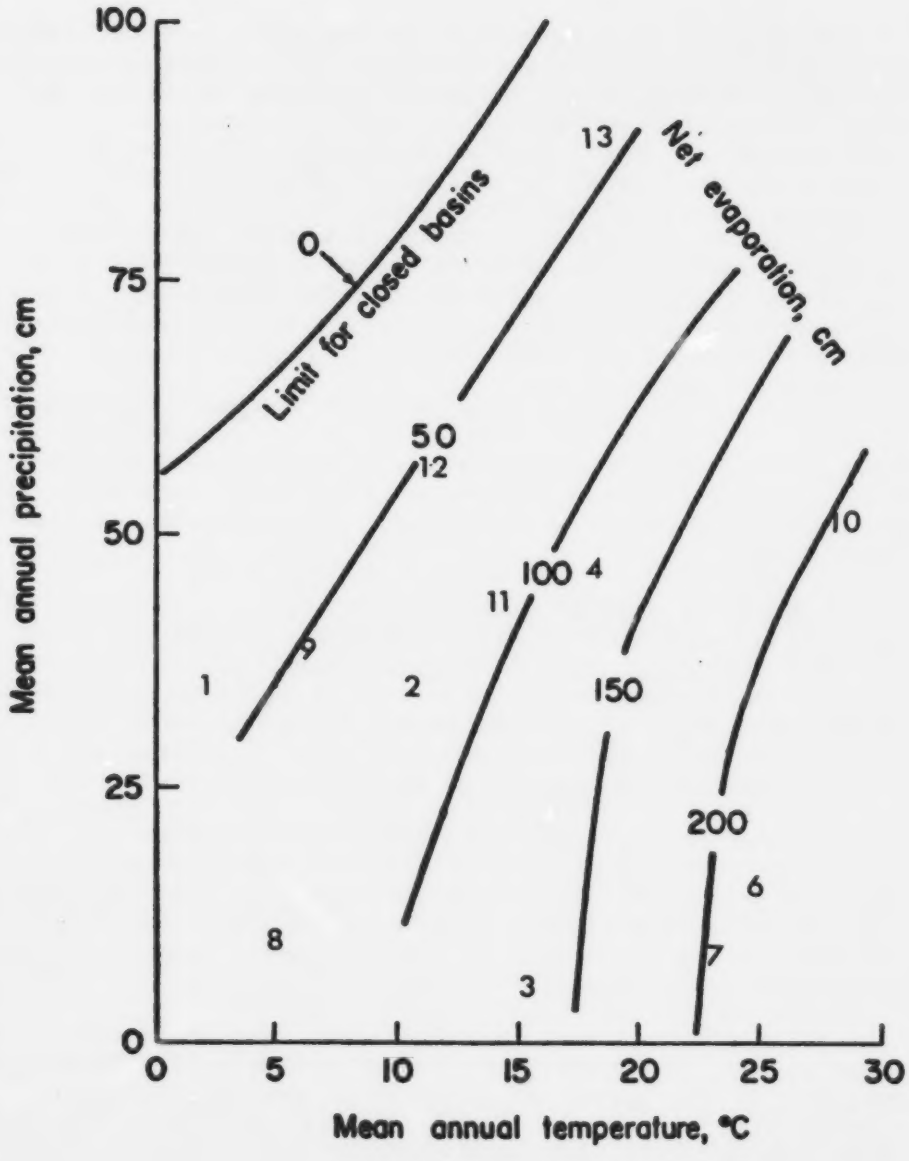


Figure 1. Closed-basin lakes related to climatic factors of mean annual temperature (°C), precipitation (cm) and net evaporation (cm) (modified from Cole 1968). 1. Big Quill, Little Manitou, Redberry lakes, Saskatchewan; 2. Great Salt Lake, Utah; 3. Salton Sea, California; 4. Lake Poopo, Peru; 5. Victorian lakes, Australia; 6. Lake Eyre, Australia; 7. Dead Sea, Israel-Jordan; 8. Lake Balkhash, U.S.S.R.; 9. Qinghai Hu, China; 10. Lakes in southern Chad; 11. Spanish saline lakes; 12. Szelider Lake, Hungary; 13. Lake Nakuru, Kenya.

Figure 2. The distribution of major endorheic (interior) drainage systems (shaded) in Alberta and Saskatchewan.

The general location of world saline lakes is presented in Figure 3. These areas parallel the climatic zones and conditions discussed above. Antarctica has been omitted. All saline lakes there occur close to the sea and the only athalassic saline lakes occur in South Victoria Land.

Salts are accumulated in lake basins through processes of salt influx in inflowing waters and concentration by evaporation. These salts may be derived from the soils and rocks of the drainage basins or through precipitation and fallout of salts accumulated in the atmosphere from sea spray or from wind-blown materials of terrestrial origin. Some saline lakes are derived from solution of ancient marine salt beds or evaporites of earlier lakes. Springs and underground flows enter many saline lakes and may be major contributors as in some lakes in East Africa (e.g. Lake Magadi). In a few cases, they are derived from activities of man associated with mining and processing

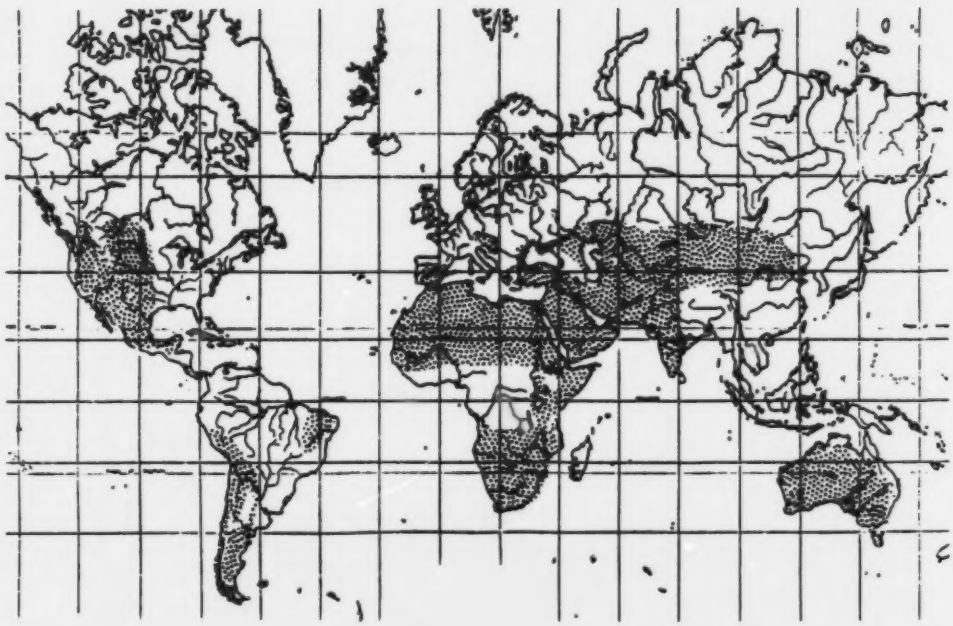


Figure 3. The distribution of dry climates of the world (stippled) where most athalassic saline lakes occur. Major deserts are also included.

of minerals. Irrigation waters maintain levels and, perhaps, the existence of many saline lakes such as the Salton Sea in California and Lake Qarun in Egypt.

TEMPORAL CHANGES IN SALINITY

The salinity of saline lakes changes with climatic changes. In pluvial times lakes were larger, had outflows and tended to be fresh. This was an effect of more precipitation or cooler temperatures or both. On the Canadian prairies the large ice-water lakes which formed from glacier melting were forerunners of present saline lakes. With higher temperatures evaporation exceeded precipitation on average, endorheic drainage developed and saline lakes were initiated.

Short term climatic changes also influence lake salinities. There is a tendency for lakes to become more saline from spring to fall as evaporation exceeds precipitation. Figure 4 illustrates annual changes in Saskatchewan lakes. Note that less saline lakes show relatively little change compared to shallow, more saline lakes. Theoretically, if the mean depth of a lake is halved by evaporation, salinity is doubled. This process is accentuated in the winter during ice formation. Salts tend to be frozen out (about 75%, Fertuck 1968)

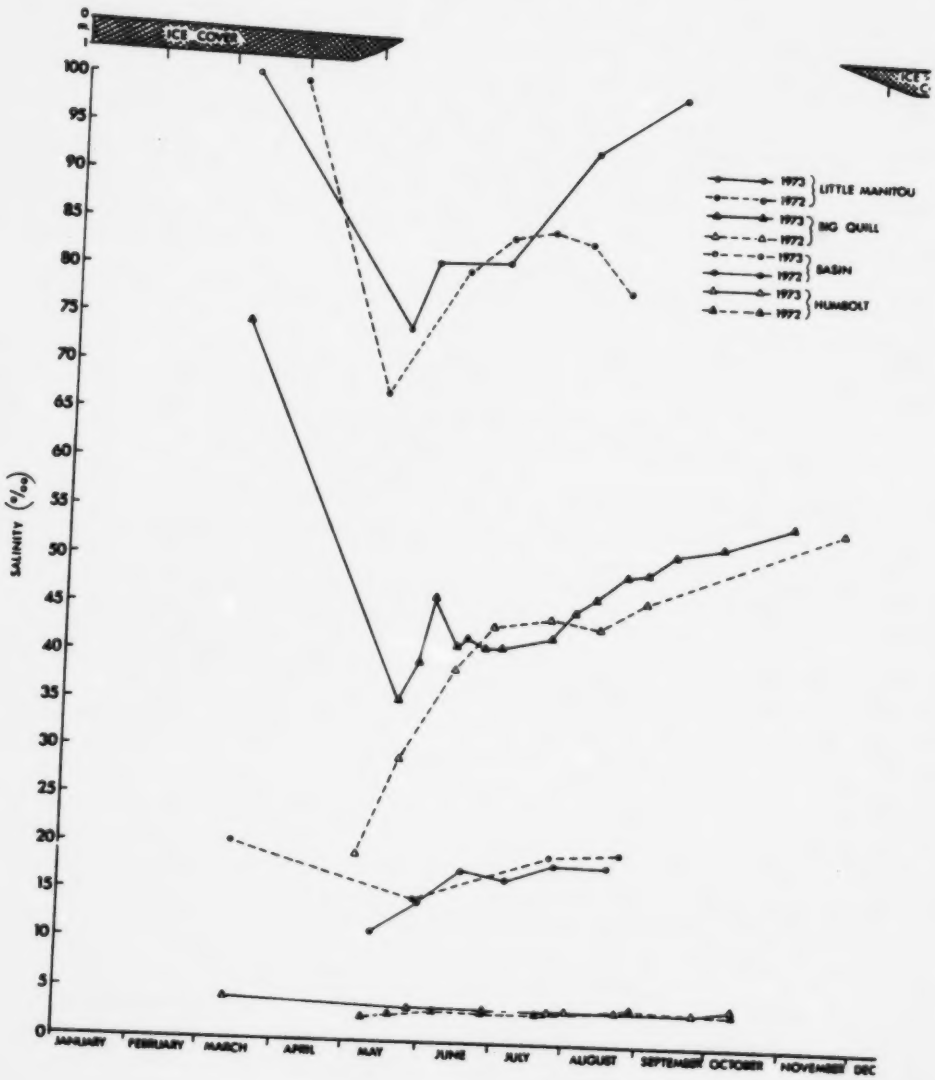


Figure 4. Temporal variations of salinity during 1972 and 1973 in four Saskatchewan saline lakes (from Hammer 1978).

so that the remaining water becomes more saline. The degree of salinization again depends on lake depth. In Big Quill Lake the water depth is reduced from 3 to 2 m when a 1 m thick ice layer is formed and this increases the water salinity about 50%. Spring snowmelt runoff tends to restore the salinity of the previous spring if the snowpack and snowmelt rate are normal. Since climate is cyclic, lake

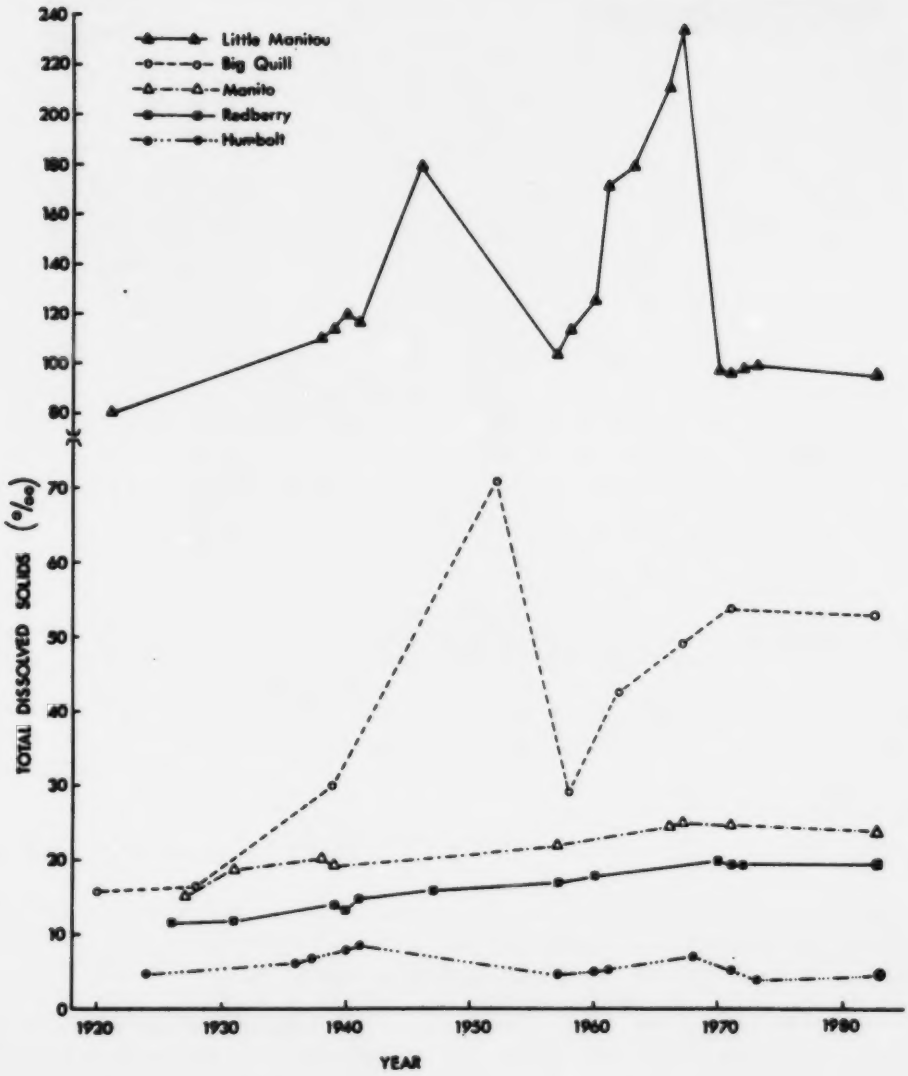


Figure 5. Long-term changes in salinity in five Saskatchewan lakes (modified from Hammer 1978).

salinity patterns are also cyclic and this is illustrated for a few Saskatchewan lakes in Figure 5. The pattern for Little Manitou Lake was interrupted by man in the late 1960s when there were inputs of water from the Saskatoon Southeast Water Distribution System. There is a long term tendency for Saskatchewan saline lakes to increase in salinity. This is a direct effect of agricultural land use which pre-

vents water from reaching lakes through the farming process itself intercepting water, or through the building of dams across streams which previously flowed into lakes. Among the best examples are Big Quill and Redberry lakes.

CHEMICAL COMPOSITION OF SALINE LAKE WATERS

Major Ions

The major cations in water are calcium, magnesium, potassium and sodium while the major anions are bicarbonate, carbonate, chloride and sulphate. In some cases other chemical constituents, such as boron or silica, may be present in large amounts. Since saline lakes tend to be dominated by sodium, with respect to cations, they are usually classified chemically according to anion dominance.

Carbonate (bicarbonate) lakes are characteristic of East Africa (Ethiopia, Kenya, Tanzania), Chad, Nebraska sandhill lakes, a few lakes in Alberta, British Columbia and Washington and many lakes on the Hungarian Plain (Austria, Hungary, Yugoslavia). Generally salinities of these lakes do not reach 100 g/L.

Chloride dominated lakes are the most widespread and occur on every continent. Chloride dominates Australian, Asian, European and South American saline lakes, as well as some in Africa and a few in North America, such as Great Salt Lake. Only three natural chloride lakes occur in Saskatchewan: two are in the Cumberland Delta, where the salt is derived from salt springs and Reflex Lake near Nielburg (Hammer 1978). A fourth, Patience Lake (up to 428 g/L), contains salt derived from potash mine tailings (Hammer & Parker 1984). The most extreme lake is that of Don Juan Pond in Antarctica which is almost pure calcium chloride with a conductivity of 790 mS/cm (338 g/L salt, 474 g/L TDS) (Meyer et al. 1962).

Sulphate dominated lakes tend to occur in North America (western Canada, the Dakotas, Wyoming, Washington) and in Asia (Soviet Siberia, northern Tibet in China, Indian Tibet), Algeria in Africa and Spain in Europe. This type of lake is absent from Antarctica, Australia or South America.

All possible intermediate mixtures of these three types exist.

Ion dominance sequences may also be used to demonstrate the relative importance of ions. The most common cation sequence is Na >Mg >Ca >K and is characteristic of more than 75% of the Asian and Australian saline lakes and more than 50% of those in Antarctica, North and South America. A second sequence, Na >K >Mg >Ca, charac-

terizes lakes in East Africa and Chad, half the lakes in western United States and a few lakes in Australia, South America and Asia. The third sequence, Mg >Na >Ca ><K, includes more than half the Saskatchewan saline lakes, lakes in northern Asia and the Dead Sea. Calcium dominance in saline lakes is only known for Don Juan Pond. Various other sequences occur but none include many lakes.

The anion lake sequence which occurs most commonly is Cl >SO_4 >$HCO_3.CO_3$. It is found in lakes on all continents and characterizes almost 50% of all saline lakes. The majority of lakes in Australia, Asia, Europe, South America and Algeria fit this sequence. Other lakes have four different sequences in approximately equal numbers. The sequence $HCO_3.CO_3$ >Cl >SO_4 characterizes lakes in East Africa, Chad, Turkey, the Hungarian Plain and western North America. The sequence SO_4 >Cl >$HCO_3.CO_3$ dominates 55% of Saskatchewan saline lakes (Hammer 1978) as well as many in western United States and in northern Asia. The SO_4 > $HCO_3.CO_3$ >Cl sequence dominates Alberta, British Columbia, Manitoba and many Saskatchewan and United States saline lake waters and is the only sequence restricted to one continent. The sequence $HCO_3.CO_3$ >SO_4 >Cl is restricted to Canada (mostly Alberta) and Chad in Africa.

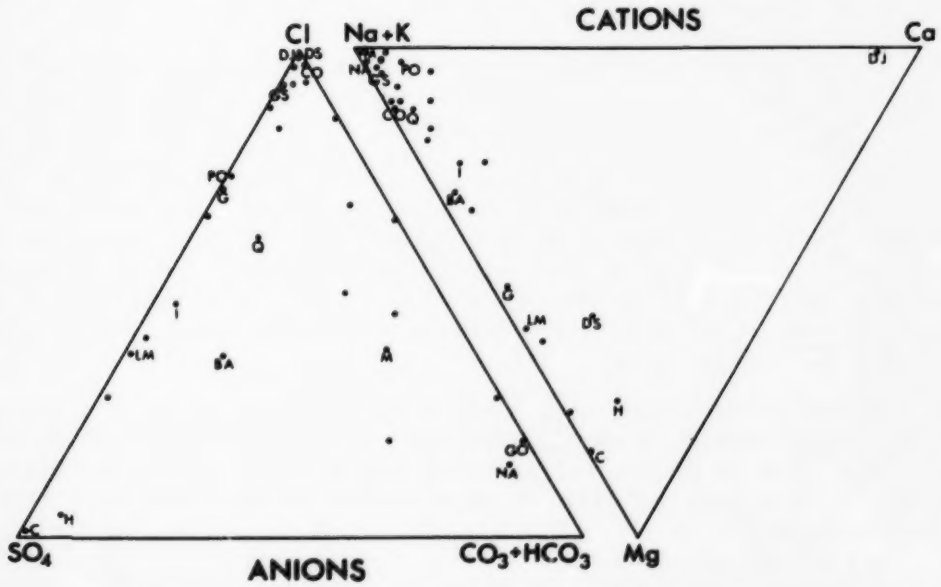


Figure 6. Ternary diagrams illustrating the distribution of major ions in world saline lakes based on milliequivalence percent. BA, Balkhash, I, Issyk Kul, Soviet Siberia; C, Clinton, GO, Goodenough, British Columbia, Canada; H, Humboldt; LM, Little Manitou, Saskatchewan, Canada; CO, Corangamite, Victoria, Australia; DJ, Don Juan, Antarctica; DS, Dead Sea, Israel-Jordan; G, Gallocanta, Spain; GS, Great Salt (South), Utah, United States; M, Mono, California, United States; NA, Nakuru, Kenya; PO, Poopo, Peru; Q, Qinghai, China. Lake Goodenough occurs in the same position as Mono Lake in the cation figure.

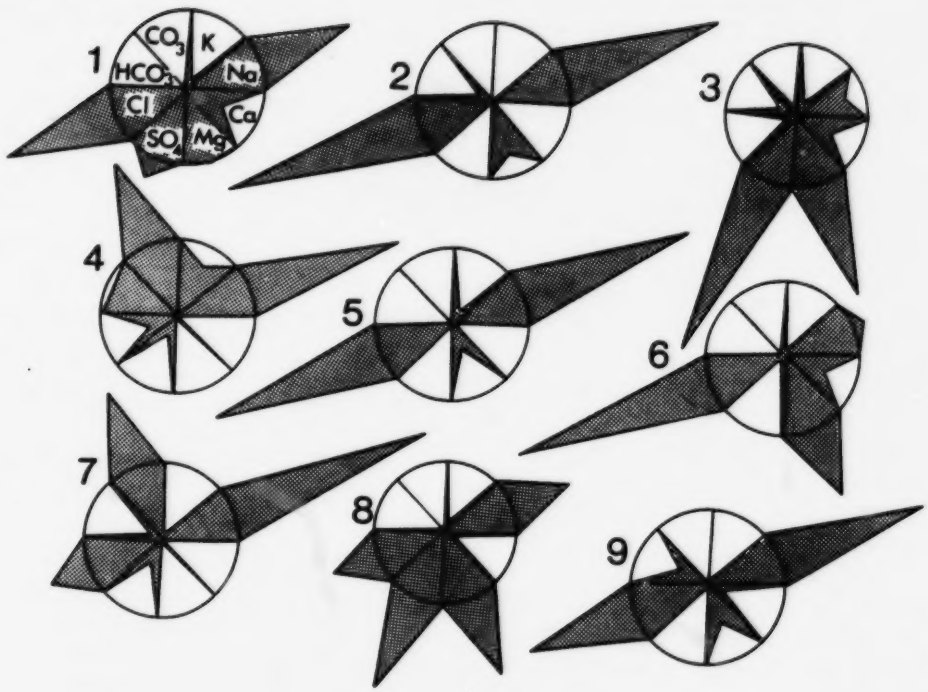


Figure 7. Maucha ion field diagrams representing typical lake chemical types. 1. Merjadaja, Algeria; 2. Corangamite, Victoria; 3. Humboldt, Saskatchewan; 4. Rombou, Chad; 5. Great Salt (South Basin), Utah; 6. Dead, Israel-Jordan; 7. Magadi, Kenya; 8. Little Manitou, Saskatchewan; 9. Qinghai, China.

The chemical variety of saline lakes is best described pictorially by ternary (Figure 6) and Maucha (Figure 7) diagrams. The tendency is for sodium and magnesium equivalences to be high with Don Juan Pond the exception (Figure 6). Sodium tends to dominate over magnesium but Saskatchewan lakes are prominent with higher magnesium. Much more scatter is evident in the distribution of anions but chloride dominates. Figure 7 illustrates the variability of ion equivalences in saline lakes.

Chemical Evolution of Closed Lakes

It is obvious that many ion dominance sequences exist and characterize saline lakes regionally. These variations, in turn, are dependent on the nature of local substrates, soils and rocks from which the

salts originate. Closed basin waters evolve as they become evaporatively concentrated. Salts precipitate out when their saturation constants are exceeded and this changes the ion proportions of the water. The evolution of salt content varies from one lake to another depending on initial ion concentrations as well as subsequent chemical processes. Figure 8 illustrates the major ion composition of inflow waters and offers a considerable contrast to Figure 6 which exemplifies the results of chemical evolution in many saline lakes. The dominant anion in inflows is bicarbonate while cations are more variable although sodium and calcium predominate.

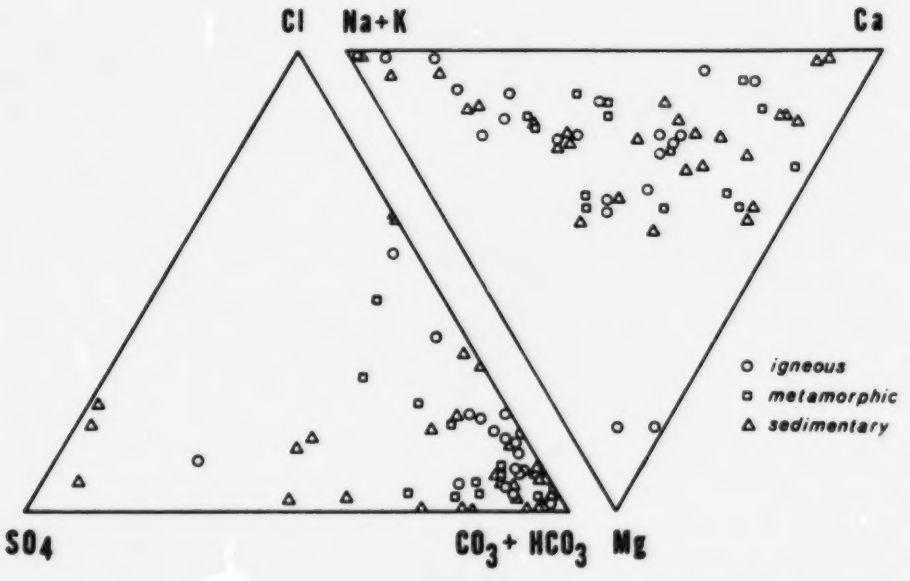


Figure 8. A ternary diagram illustrating the major ion composition of inflow waters grouped by drainage basin lithology (from Eugster & Jones 1978).

As waters become chemically concentrated (more saline), solutes become depleted. Magnesium and calcium co-precipitate with carbonates as calcite and aragonite ($CaCO_3$) and dolomite [$CaMg(CO_3)_2$] (Figure 9). An important early branching point depends on whether bicarbonate-carbonate is in excess, less than, or equal to calcium plus magnesium. If considerable bicarbonate-carbonate remains after most of the calcium and magnesium have been removed, these anions will continue to increase with further evaporative concentration and bicarbonate-carbonate dominant saline lakes result, e.g. Hungarian lakes; Lake Nakuru, Kenya; Goodenough Lake, British Columbia. At high concentrations trona ($Na_2CO_3.NaHCO_3.2H_2O$) or soda is precipitated and may provide the basis for a soda mining industry (Lake Magadi, Kenya). High

bicarbonate-carbonate concentrations tend to become characteristic of volcanic regions, and, in contrast to other saline lakes pHs tend to become very high (i.e., up to 11).

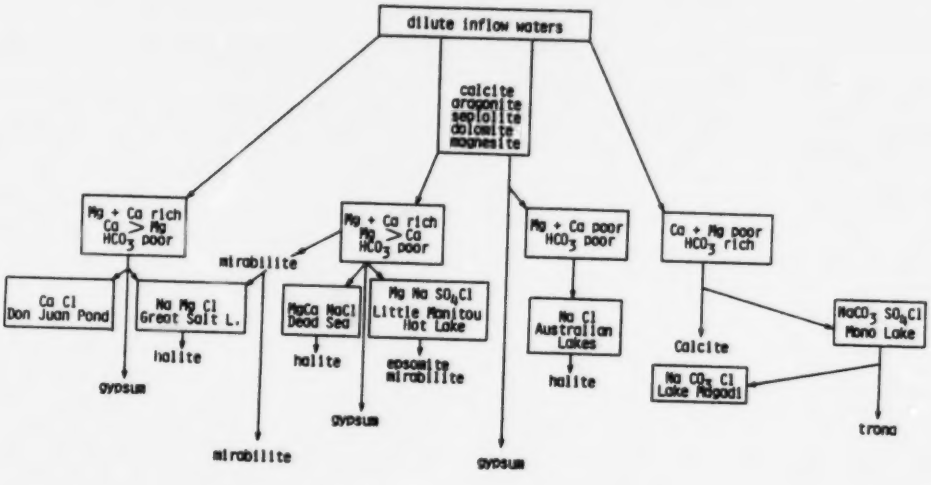


Figure 9. Flow diagram for the chemical evolution of closed lake basin waters (boxes) and their mineral precipitates.

If, on the other hand, bicarbonate-carbonate is depleted first, low alkalinity saline lakes result. If silica is high, sepiolite ($Mg_2Si0_3.nH_20$), is also one of the early precipitates. The next mineral to precipitate is gypsum ($CaSO_4.2H_2O$) and its occurrence is dependent on the presence of calcium and sulphate. Typically, many Australian lakes have dunes of gypsum in their vicinity while the waters are almost completely depleted of the two ions. Therefore, if carbonates-bicarbonates, silica and sulphate anions and calcium and magnesium cations ions are depleted the conservative chloride and sodium remain and continue to increase, resulting in sodium chloride lakes which are prevalent around the world. Halite (NaCl) precipitates when the concentration exceeds 357 g/L. This occurs in the Dead Sea, the northern basin of Great Salt Lake, many Australian lakes and Patience Lake in Saskatchewan, and is an important basis for the salt industry in many countries (e.g. Australia, Turkey, Soviet Union).

If the sulphate content of inflow waters is high, sulphate will continue to increase with further evaporative concentration since the solubility of its salts are relatively high and only slightly lower than that of halite. Mirabilite ($Na_2SO_4.10H_2O$) is precipitated when the temperature is lowered in the fall (Little Manitou Lake, Great

Salt Lake) but is redissolved when the temperature rises in the spring. If evaporation is complete in shallow lakes thenardite (Na_2SO_4) is the evaporite. If magnesium is present in considerable amounts (Muskiki Lake), epsomite ($MgSO_4.7H_2O$) is precipitated. The most soluble minerals involve magnesium and calcium chlorides but since the surplus of all of these cations at high salinites is unusual, lakes with dominant concentrations of these ions are unusual. It should be noted that biogenic production of carbon dioxide and/or hydrogen sulphide may play important roles in altering the direction of chemical evolution.

The end effect of increasing concentrations of salts in saline lakes, is a series of layers of different salts in the sediments. Reversal may occur if fresh waters flow into the lake and salt sediments may, in part, be redissolved. A well documented example of the process is for Lake Eyre, Australia, where complete dissolution of the salt sediments required 18 months after the major filling in 1974 (Dulhunty 1977). Deposited salts may be covered by other materials which are produced within the lake or brought in with inflows (detritus, clays) and this may prevent complete dissolution. If a playa lake is evaporated to dryness, deflation by wind may occur. Clouds of sodium sulphate are common during dry windy periods on the Canadian prairies. These processes reduce the salinity of the lake when it becomes refilled through precipitation and runoff. Thus the chemical and physical processes which determine lake salinities are dynamic and stability is unusual.

Other Chemical Parameters

As noted above the pH rises with increased alkalinity but this is irrespective of salinity. In chloride lakes the tendency is for pH to decrease with increasing salinity. This is not particularly evident in sulphate lakes.

The capability of water to retain dissolved gases is reduced as the salinity increases. This is of little importance for most gases but oxygen concentrations may become very low, about 1-2 mg/L, when lakes attain concentrations of over 300 g/L salt.

Great variability is characteristic of saline lakes with respect to nutrient elements dissolved in the water. Hutchinson (1957) noted phosphorus polytypy as characteristic of saline lakes. Hammer (1978) corroborated this for Saskatchewan saline lakes but there are exceptions, particularly in highly saline lakes where phosphorus may be limiting, as in Pink Lake, Australia (Hammer 1981a). Very high natural values have been recorded for some lakes, such as Goodenough Lake, British Columbia (208 mg/L total P, Clarke 1924) and Red Rock Tarn, Australia (26 mg/L soluble P, Hammer 1981a). The range in

saline lakes is greater than that in freshwater and subsaline lakes even when the latter have been polluted by man.

Other nutrients have ranges which are similar in saline lakes and non-saline lakes.

PHYSICAL ASPECTS

Variations in physical factors, such as light penetration and water transparency, water colour, turbidity, heat budgets, mixing types and thermal stratification, are similar in saline lakes and non-saline lakes.

Most meromictic lakes are saline, at least in part. Antarctic meromictic lakes tend to be fresh at the surface (below the ice cover) but saline at deeper depths. Some of these lakes are much warmer in deeper water (25°C at 64 m in L. Vanda, Antarctica, Torii et al. 1975; 40°C in Hot Lake, Washington, at 2 m depth but 18°C at the surface, Anderson 1958).

Increasing salinity tends to permit higher water temperatures as the salt also absorbs solar energy, as occurs in Patience Lake (Hammer & Parker 1984). Increasing salinity also depresses the freezing point. Meyer et al. (1962) noted that the freezing point of Don Juan Pond water was -48°C while Patience Lake does not freeze until its temperature is lowered to -24°C (Hammer & Parker 1984). Ice cover tends to be thin on these chloride lakes when they do freeze. This supercooling must, presumably, affect and perhaps eliminate most aquatic life from these lakes. Although the freezing point of sulphate lakes is also depressed, freezing out of salts permits freezing and the estabishment of normal ice cover.

BIOLOGICAL ASPECTS

Hyposaline lakes are characterized by a very diverse flora and fauna. There is a drastic decrease in the number of species with increasing salinity in mesosaline waters and a further decrease as the waters become hypersaline and approach saturation (Figure 10). This is a distinct contrast to marine waters which have a high number of species.

Although many species of higher plants dominate the littoral of hyposaline lakes, species numbers are quickly reduced with increasing salinity. Only Potamogeton pectinatus, Ruppia maritima and R. occidentalis also occupy hypersaline salinities in North America. The same or ecologically equivalent species are found in similar salinities in the Palearctic. In Australia P. pectinatus and R. maritima

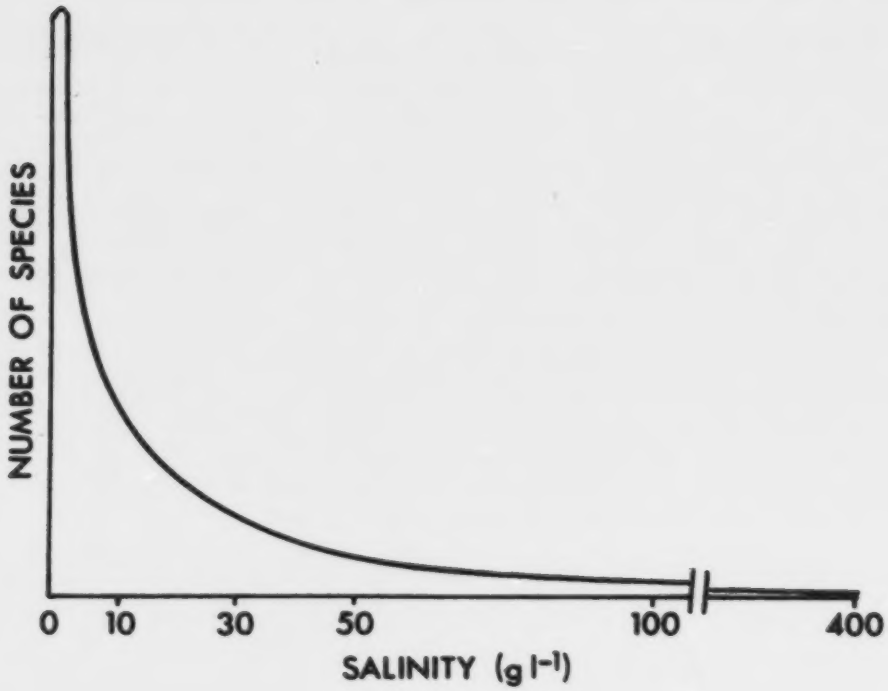


Figure 10. The effect of increasing salinity on numbers of species in athalassic saline lakes.

mostly occur in subsaline waters but other species of Ruppia are found in very high salinities (up to > 100 g/L). The charophyte Lamprothamnium papulosum also occurs there in similar salinities.

Hyposaline and mesosaline carbonate-bicarbonate waters tend to be dominated by blue-green algae. In East Africa and Chad Spirulina platensis is the dominant alga and is so dense that it forms the principal food of the lesser flamingo. In Australia, Anabaena spiroides, is dominant in more alkaline lakes. In Lake Corangamite (Australia), Manito Lake (Saskatchewan) and Pyramid Lake (Nevada) Nodularia spumigena is dominant. In hypersaline lakes green filamentous algae and diatoms become dominant. For example, in Saskatchewan lakes Rhizoclonium hieroglyphicum and Ctenocladus circinnatus are dominant and the same or related species play similar roles in the Soviet Union, China and South America. Diatoms are very important in the plankton and on the substrates of highly saline lakes. Amphora coffaeiformis, Chaetoceros elmorei, Cocconeis placentula, Cyclotella meneghiniana, Navicula cincta, N. cryptocephala, Nitzschia acicularis and N. palea are found in abundance in lakes of at least three continents each and

all occur in Saskatchewan saline lakes (Hammer et al. 1983). A green flagellate, Dunaliella salina, is characteristic of highly saline lakes the world over and may be the only important photosynthetic organism in such lakes. It is able to tolerate such high salinities by producing glycerol in which its enzymes can function even when external environments are highly saline.

Primary productivity of saline lakes ranges from extremely low (Pink Lake, Australia; Patience Lake, Saskatchewan) to extremely high levels (Lake Aranguadi, Ethiopia; Lake Mariut, Egypt; Red Rock Tarn, Australia) which exceed productivities in any non-saline lakes (Hammer 1981a, b).

Some rotifer species are able to tolerate a broad spectrum of salinities up to 100 g/L (e.g., Brachionus plicatilis, Hexarthra fennica), while a few others can tolerate high alkalinities (e.g., Hexarthra jenkinae). These rotifers tend to be cosmopolitan. Among the crustaceans, some copepod species may tolerate salinities up to more than 100 g/L (e.g., Calamoecia species in Australia, Europe, Asia, North America). Cladocerans tend not to be found in hypersaline waters. These groups are much less cosmopolitan than the rotifers. The brine shrimp, Artemia salina, is found in highly saline lakes around the world but may be successful even in hyposaline waters where copepod predators are absent (Bayly 1967, Hurlbert, pers. comm.). It is successful in highly saline waters because it can maintain its internal osmotic concentration well below that of the medium in which it lives. It also contains haemoglobin which allows it to survive at high salinities where oxygen content is low. Its ecological equivalent in Australia is Parartemia zietziana which lacks haemoglobin and is therefore less successful at very high salinites (Geddes 1981). Brine shrimp and their eggs are harvested from Chaplin, Little Manitou, Great Salt and Mono lakes in North America for the tropical fish food market.

Species numbers of benthic fauna also decrease with increasing salinities. Mollusks are relatively unsuccessful in saline waters except for Coxiella striata in Australia. In that country ostracods dominate the fauna and some species can tolerate salinities up to greater than 150 g/L (De Deckker 1981). This group tolerates much lower salinities elsewhere although a few species live in hypersaline Saskatchewan lakes, such as Lymnocythere staplini, Megalocypris ingens (Delorme 1965).

Aquatic insects, particularly species of Diptera, are very important in saline lakes in the northern hemisphere. The most salt tolerant species, similar to brine shrimp tolerance, are the ephydrids such as Ephydra cinerea which dominates Great Salt Lake and E. hians which is abundant in highly saline Saskatchewan lakes and Mono Lake, California. These may be so abundant that they interfere with recrea-

tional pursuits in some lakes such as Great Salt Lake (Haws et al. 1977). In hyposaline and mesosaline lakes corixids and chironomids play major roles. Amphipods are more important in hyposaline lakes (Gammarus lacustris, Hyallela azteca in North America, Rawson & Moore 1944) although they also occur in mesosaline waters as do Austrochiltonia species in Australia (Williams 1981).

Fish species tend to be restricted to hyposaline waters with a maximum of about ten species in any particular geographic region. In Africa some cichlid fish are very successful in mesosaline waters but some commercial species have been introduced from marine habitats, e.g., Lake Qarun, Egypt (El-Zarka 1968). The most salt tolerant fish are the cyprindonts which have been found in salinities up to about 145 g/L (Cyprinotus variegatus, Simpson & Gunter 1956 in the United States; Aphanius dispar in the Middle East, Lotan 1971).

Waterfowl are important with respect to saline lakes. The most famous are the flamingos of Africa and the South American Altiplano (a high plateau between ranges of the Andes). These birds vary from species which filter-feed on algae (blue-greens, diatoms) and rotifers to species which feed on aquatic insects, amphipods and brine shrimp (Vareschi 1978, Hurlbert et al. 1984). A great variety of other aquatic birds utilize saline lakes for feeding, nesting, resting and staging on all continents except Antarctica. Relatively little is known or has been published concerning aquatic birds and prairie saline lakes in Canada.

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SALINE LAKE MANAGEMENT FOR WATERFOWL RESOURCES IN WESTERN NORTH AMERICA: A REVIEW OF CONCEPTS

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ABSTRACT

Wildlife managers and ecologists have used a variety of approaches to estimate water salinity. Thorough laboratory analyses of ion composition are recommended, so that research results may be reliable and comparable. The terms "alkali" and "alkaline" are often misused in describing inland saline wetlands. Most authors have selected either 3,000 or 5,000 mg/L TDS (total dissolved solids) as the dividing point between saline and non-saline waters. Based on human use standards, we select 5000 mg/L, and term waters with TDS above this "poimenochoric." Waterfowl use highly saline lakes throughout western North America. Salt glands allow ducks to use these waters, but supplemental fresh water may be necessary. Saline wetlands produce abundant plant and animal food for ducks. Current management of saline lakes emphasizes water level control for production of food and cover and for prevention of botulism outbreaks. Impoundments could be build in saline lakes to concentrate fresh water inflow for waterfowl use. Blending of fresh and saline waters might be used to promote aquatic plant growth. Toxic irrigation return flow has caused problems in saline wetland management. Small saline wetlands could be enriched through plantings, and protected from livestock by fencing.

Any wildlife biologist interested in managing saline wetlands is confronted with two problems of measurement: what is "salinity" as a parameter; and what is a "saline" wetland? Our review of studies on the relationship between higher aquatic animals and plants, versus water salinity, indicated there is a lack of uniformity in estimating and defining these parameters - making comparison of results very difficult. Thus, a brief discussion of these concepts seems an appropriate introduction to this review.

THE MEASUREMENT OF SALINITY

As Reid (1961) noted, nearly all of the naturally occurring elements can be found in inland waters, but some inorganic materials appear much more frequently. The major constituents in North America include the anions CO_3 + HCO_3, SO_4, Cl, and NO_3, the cations Ca, Mg,

Na, and K, and SiO_2 (Clarke 1924). Reid stated that salinity of fresh waters is defined as the total concentration of the ionic components. During evaporative concentration, the major ions of CO_3, SO_4, Cl, Ca, Mg, Na and K may combine in various ways to form some 20 major minerals meeting the chemical definition of "salt" (Eugster and Hardie 1978). What the layman thinks of as "salt" (halite - NaCl) is only one of these.

Since these major ions make up most of the dissolved solids in natural waters, the measurement of total dissolved solids (TDS) is a way of closely estimating salinity. The solution is filtered to remove suspended solids, then water is evaporated. The residue is then heated to drive off volatile organic substances. Some bicarbonates may be decomposed through loss of CO_2 (Reid 1961). After this "loss on ignition," the amount of residue is expressed as mass per liter of the original water sample. A common unit is mg/L, although the terms parts per million (ppm) or parts per thousand (ppt) by weight are used.

Another estimate of salinity may be made through measuring the electrical conductivity of the solution. The parameter "specific conductance" is determined by calculating the reciprocal of the resistance measured between two electrodes separated by 1 cm and having a cross sectional area of 1 cm^2 (Reid 1961). Specific conductance is usually expressed as micromhos/cm at 25°C. Water conductivity meters are readily available commercially, and measurement of specific conductance is relatively quick and inexpensive. The principle underlying conductivity measurements is that the higher the concentration of ions in solution (salinity), the higher will be the specific conductivity. While, very generally, this is true, some wetland managers seem to have assumed that there is a linear relationship between the two parameters (see Neely 1962, and Cowardin et al. 1979, for examples). In fact, however, as the concentration of a saline solution increases to high levels, the proportion of free ions decreases, and the rate of increase in conductivity drops off (Stewart and Kantrud 1972: Table 2).

There is great variation in the proportions of the major cations and anions in various saline lakes (see Table 1 of Eugster and Hardie 1978, and Table 1 of Hammer 1978, for many western North American examples). Due to differences in the degree of ionization of various salts and interactions between compounds in solution, it is not uncommon to find waters which have similar amounts of total dissolved solids, yet have quite dissimilar specific conductance (for example, compare Arthur and Louis lakes in Hammer 1978).

Since it is the actual concentration of particular ions, rather than simple conductivity of a solution, which primarily determines biological effects on aquatic organisms, wetland managers should not

rely solely on conductivity measurements when proposing cause and effect relationships between salinity and species distribution. Since various ions may have different, at times toxic, effects on different species of plants and animals (Harnisch 1951; Bernstein and Hayward 1958; Macan 1960), simple measurement of TDS may not be adequate. A thorough laboratory analysis of ion distribution, such as described by Hammer (1978), is essential. Simple conductivity or TDS measurements may, however, be useful in studying changes within an individual saline wetland or in some marine estuarine systems.

CLASSIFICATION OF SALINE WETLANDS

Dissolved solids in inland wetlands range from as low as 10-20 mg/L (Clarke 1924) up to nearly 400,000 mg/L in concentrated brines (Eugster and Hardie 1978; Last and Schweyen 1983). Saline conditions most often occur within endorheic drainage basins where outflow is restricted and evaporation rates are high (Eugster and Hardie 1978; Hammer 1978, Williams 1981). Any type of wetland, including temporary open pools (playas), marshes with emergent aquatic vegetation and permanent open water lakes, with or without submerged aquatic plants, may have high concentrations of dissolved solids (Stewart and Kantrud 1971; Cowardin *et al.* 1979).

Two widely-used schemes for classifying wetlands on a regional or national (U.S.) basis have included salinity factors. Stewart and Kantrud (1971) suggested six unequal electrical conductivity categories, from fresh (<500 micromhos/cm) to saline (>45,000 micromhos /cm), but no dividing point was selected. Cowardin *et al.* (1979) modified the "Venice System" to produce six unequal salinity categories based on total dissolved solids, but no critical level was identified.

Cowardin *et al.* (1979) rejected the term "brackish," and suggested using "haline" for coastal waters dominated by "ocean salt" (NaCl), as opposed to "saline" for inland waters of varying ionic dominance. However, since some inland saline lakes are dominated by sodium chloride (Eugster and Hardie 1978; Hammer 1978), and are "thalassohaline" - similar chemical proportions to sea water (Bond 1935), use of the term "haline" only for ocean-connected waters seems questionable. Instead, the simple terms "inland" (the "athalassic" of Bayly 1967), or "estuarine" (thalassic) might suffice for this purpose.

Two other terms sometimes used in reference to saline lakes are "alkali" and "alkaline." Alkali metals, such as Na and K, are frequently-encountered ions in saline waters. Hence, when the wetlands recede through evaporation, white alkali salts may form on the lake margins and the water body may be loosely referred to as an "alkali"

lake or marsh (Moyle 1945). However, since many non-alkalisalts also may be in the solution, use of this term, "total alkali content," as a substitute for total salinity is misleading. A second feature of inland saline waters is that they almost always have alkaline pH values (see Eugster and Hardie 1978 and Hammer 1978 for examples). Because of this, some biologists use "total alkalinity" as a synonym for total salts (McAtee 1939). A rule for wetland managers to remember might be that highly saline wetlands are nearly always alkaline, but alkaline waters are not always highly saline. The best way to characterize inland saline waters is through use of ionic descriptions, such as "magnesium (sodium) sulphate type," with appropriate diagrams of the relative quantities of major ions. Two ways of doing this are given in Eugster and Hardie (1978), Hammer(1978), and Last (1984).

Beadle (1981) indicated that truly saline waters must be concentrated enough to produce "profound biological effects." This concept has been used by others but with differing conclusions. A low figure of 300 mg/L TDS was selected by Rawson and Moore (1944). Williams (1964), Bayly (1973), Hammer (1978), and Last and Schweyen (1983) used a minimum value of 3000 mg/L to designate saline concentrations. Eugster and Hardie (1978), Beadle (1981), and Last (1984) accepted 5000 mg/L as the dividing point between fresh and saline waters.

Although the idea of "profound biological effects" (on native organisms) is appealing, analysis of the tolerance of organisms to increasing salinity seldom reveals clear-cut dividing points (see Stewart and Kantrud 1972, for vascular plant examples). Human drinking water standards range from a preferred maximum of 500 mg/L up to an absolute maximum of 5000 mg/L (U.S. Dep. Health, Educ. and Welfare 1962, U.S. Environ. Prot. Agency 1979). In semiarid regions, where dissolved solids may gradually accumulate in the soil profile,irrigation water TDS concentrations of only 500-1000 mg/L may be unacceptable for common agricultural crops (U.S. Dep. Agric. 1969). Livestock, except for poultry and swine, may tolerate salinities of up to 10,000 mg/L (National Academy of Sciences 1974), although over 5000 mg/L is considered unsatisfactory (U.S. Environ. Protect. Agency 1979).

From an aesthetic standpoint inland wetlands with salinities above 5000 mg/L often are not things of beauty. They usually have little emergent vegetation, salt-encrusted shorelines, a characteristic disagreeable odor, and they do not interest fishermen or agriculturalists. These wetlands might be characterized by the term "poimenochoric" - roughly meaning they are of no use to the shepherd or his animals. A result of this status is that such wetlands are prime candidates for drainage - especially in North American regions where they are, often incorrectly, suspected of being "recharge areas" for saline seeps (Hanson 1976; Thacker 1976; Miller and Bergantino 1983). As with earlier wetland drainage projects in other regions, the value of

poimenochoric inland saline wetlands for waterfowl has been largely overlooked. In the following sections, we hope to document some of these waterfowl values and summarize the few management techniques that have been used on poimenochoric saline wetlands. Lastly, we will discuss some untried potential techniques for management of these wetlands.

WATERFOWL USE OF INLAND POIMENOCHORIC SALINE WETLANDS

Waterfowl have the opportunity to utilize highly saline inland waters when nesting, migrating, and wintering in western North America. Every state and province west of the 100th meridian contains saline wetlands (Driver 1965; McCarraher and Thomas 1968; Stewart and Kantrud 1971; Thacker 1976; Eugster and Hardie 1978; Hammer 1978; Guthery and Bryant 1982) and they are especially abundant in the northern plains of Alberta, Montana, North Dakota, and Saskatchewan. Shaw and Fredine (1956) estimated that there were over 650,000 ha of saline wetlands in the U.S. alone. It is apparent that saline wetlands constitute a significant potential resource for waterfowl.

Several species of ducks have been reported nesting near and rearing broods on North American saline lakes having up to about 50,000 mg/L TDS (Jensen and Chatin 1964; Duebbert et al. 1983; Swanson et al. 1984). Nesting densities of 100 nests/ha or more have been observed, particularly on small islands (Sanderson and Bellrose 1969; Browne et al. 1983; Lokemoen et al. 1984). These lakes may be so highly preferred that unusual nesting cover, such as shrubs, may be heavily used by dabbling ducks (Duebbert et al. 1983). In the absence of emergent aquatic plants, over 70% of the redheads (Aythya americana) and ruddy ducks (Oxyura jamaicensis) nested on dry land around a Utah saline marsh (McKnight and Low 1969; McKnight 1974) - this contradicts the accepted thinking about nesting requirements for these species (Low 1945; Lokemoen 1966). In 1983-84, lowering water levels created a small natural island in Big Lake, south central Montana. In the spring of 1984, "several hundred" nests, including those of lesser scaup (Aythya affinis), were found on this relatively bare island (R. Fliger, Montana Dep. Fish Wildl. and Parks, pers. comm. 1985).

Although ducklings may readily use highly saline lakes, there are some limitations. Ducks can exploit highly saline habitats because of structures called supraorbital salt glands. Excess salts in the body fluids are concentrated by the glands and secreted through the nasal passages (Ellis et al. 1963; Cooch 1964). When a duckling hatches, however, the salt glands are not functional. It takes about 6 days for them to enlarge and become active, if the bird is subjected to some salt stress (Ellis et al. 1963; Riggert 1977). During this period, ducklings are much less tolerant of NaCl in their drinking water than after acclimation. Schmidt-Nielson and Kim (1964) and

Riggert (1969) found young ducklings were intolerant of NaCl solutions above 5,000 mg/L. Paralysis and death were likely results when such concentrations were given to unacclimated ducklings. If, however, ducklings have access to fresh water during a several-day acclimation period, they may eventually be able to consume water with up to 20,000 mg/L NaCl, without significant fresh water supplements (Riggert 1977). Response to other salts is unknown, and may vary.

A direct result of the duckling's need for fresh water during an acclimation period is that the adult female must lead her brood to a fresh water source. In some cases, the female may lead the brood to fresh water springs or streams on the saline lake margin (Swanson et al. 1984). Movements to such areas may be as far as 9.5 km (Riggert 1977). Another strategy is for the female and brood to completely leave the saline lake, and seek other fresh water sites (Lokemoen et al. 1984). Movements of this nature to wetlands up to 5 km distant have been recorded for mallards (Anas platyrhynchos) and gadwalls (Anas strepera) (Duebbert et al. 1983).

Saline lakes are widely used by adult waterfowl for feeding and resting during all seasons (Gates 1962; Malheur Nat. Wildl. Refuge 1967; Serie and Swanson 1976; Books 1983). Adults, except during the annual postnuptial molt in summer, are highly mobile and usually able to find fresh water if they need it. From Riggert's (1977) data for mountain ducks (Tadorna tadornoides), ducks feeding in (NaCl) saline lakes with more than 20,000 mg/L TDS must have a source of fresh water with which to flush out the salt gland and renal system, in order to maintain an electrolyte balance. The response of adult ducks to various ionic concentrations found in different inland wetlands is unknown. Work by Schmidt-Nielson (1960) and Riggert (1969) suggests that duck salt glands are best able to process Na and Cl, followed by K and HCO_3, and that the glands may be unable to remove Mg and SO_4. If this is true, ducks utilizing inland saline waters may need fresh water daily even when the saline waters are well below 20,000 mg/L TDS, since Mg and SO_4 are very common constituents of highly saline inland waters (Eugster and Hardie 1978; Hammer 1978; Last 1984). This is a good example of why it is important to quantify the ionic composition of saline waters, rather than using simple conductivity or TDS measurements, in determining the wetland's suitability for waterfowl use. It is especially important if no fresh water sources (less than 5,000 mg/L TDS) are available within 10-15 km of the saline wetland. The tolerance of young and adult ducks to different ionic solutions commonly found in inland waters needs considerable research.

If fresh water is available for flushing the bird's system, there appears to be almost no boundary (within chemical saturation limits) to the salinity of waters which ducks may use. Swanson et al. (1984) found young and adult ducks feeding in wetlands with over 50,000 mg/L TDS, and Riggert (1977) reported that young and mature birds fed at lakes having as high as 245,000 mg/L NaCl.

Regardless of total salinity, a poimenochoric inland wetland must produce abundant food items if the wetland is to be of significant benefit to waterfowl. Vascular hydrophytes provide an important part of the diet of waterfowl in many saline wetlands (Metcalf 1931; McAtee 1939; Neely and Davidson 1971; Serie and Swanson 1976). Numerous attempts have been made to classify higher aquatic plants according to their salt tolerance (Metcalf 1931; McAtee 1939; Moyle 1945; Neely 1962; Christiansen and Low 1970; Stewart and Kantrud 1972). Because most workers have not carefully correlated plant growth with specific ion analysis of the water, results have been inconsistent and it is impossible to make comparisons between some studies. Metcalf (1931) observed that sago pondweed (Potamogeton pectinatus) grew well in North Dakota lakes having TDS of 35,873 mg/L or more; but the composition of the waters was unknown. Conversely, Christiansen and Low (1970) grew this plant in NaCl solutions, and reported that young plants did not establish themselves at concentrations above 9,000 mg/L. Stewart and Kantrud (1972) reported that alkali bulrush (Scirpus paludosus) grew well at salinities exceeding 45,000 micromhos/cm in North Dakota, while Christiansen and Low (1970) found NaCl solutions above 21,200 micromhos/cm were harmful to this same species. Limited attempts to relate plant growth to specific ion composition have been made by Moyle (1945) and Stewart and Kantrud (1972). There are about 20 species of emergent and submerged aquatic plants and 10 shoreline halophytes that are of use as food and cover to waterfowl which frequent poimenochoric inland saline wetlands in western North America. The upper limit of tolerance for useful food plants seems to be about 75,000 mg/L TDS, which can support widgeongrass (Ruppia maritima) (Metcalf 1931). Waterfowl using wetlands more saline than this must generally rely upon invertebrate animals for food.

A wide variety of insects, crustaceans, and molluscs are used as food by ducks feeding in inland saline waters (Swanson et al. 1974; Serie and Swanson 1976; Kantrud and Stewart 1977; Duebbert et al. 1983). A number of invertebrate species can live in extremely saline waters, including concentrated brine solutions (Beadle 1981). One preferred food of ducks is brine shrimp (Artemia salina) (Serie and Swanson 1976; Duebbert et al. 1983). These may be found in abundance in such saline waters as Great Salt Lake, Utah (Beadle 1981), which has a salinity of about 254,000 mg/L (Eugster and Hardie 1978). Almost any highly saline lake can produce food for waterfowl, if conditions are favourable for appropriate invertebrates.

CURRENT INLAND SALINE WETLAND MANAGEMENT FOR WATERFOWL

Control of water levels is the most important method used to manage wetlands for waterfowl. By manipulating water levels, the manager may alter ecological succession in the wetland to favour plants and animals that are beneficial to waterfowl. Dikes, levies

and canals have been built on a number of large saline wetlands in the West to aid in water level control (Sanderson and Bellrose 1969; Books 1983; Kadlec and Smith 1984). Water may be added to or removed from areas through the use of gravity-fed control structures such as dams, weirs and flapgates, or by pumping. The Malheur National Wildlife Refuge, in Oregon, has used drawdowns and pond drying to aereate bottom soils and stimulate germination and growth of emergent aquatic vegetation (Malheur Nat. Wildl. Refuge 1967). Conversely, water levels were raised 8 cm in a marsh near Great Salt Lake, in Utah, to flood new areas and encourage submerged aquatic food plants (Robel 1962). At the Fish Springs National Wildlife Refuge, in Utah, managers drained impoundments on a rotational basis during the late summer months. Reflooded units produced greater numbers of aquatic insects the next year than did continuously-flooded units. The manipulated units also supported greatly increased numbers of duck broods (McKnight and Low 1969).

A second reason for manipulating water levels at saline lakes is to control the "Western Duck Sickness" disease of botulism, which can kill hundreds of thousands of ducks (Eustace 1981). The disease is caused by a toxin produced by the bacterium Clostridium botulinum type C, which thrives under anaerobic conditions. These conditions are produced within the bodies of terrestrial or aquatic insects, which may be killed when lakes rise or fall, respectively. The bacteria may also develop in the carcasses of ducks that have died from other causes. Fly maggots, feeding on the carcass, ingest the toxic bacteria and become poisonous (Coburn and Quortrup 1938, Bell et al. 1955; Hunter 1970). Serious outbreaks of botulism occur during the hot summer months when lakes may slowly fall; while at other times, rising water causes duck kills. In either case dead insects or live fly maggots are made available for ducks to consume. Saline lakes have long been associated with serious botulism outbreaks (Kalmbach 1968). These lakes are often quite shallow and located in flat closed basins, so evaporation or rainstorms can cause marked changes in the water level and shoreline. These fluctuations generate the dead, toxic insects. Botulism problems are further aggravated at highly saline lakes because the toxin interferes with the operation of duck salt glands. A sublethal dose of toxin may cause a decrease in flow of salt solution from the glands and ducks may die of salt toxicity (Cooch 1964).

Although botulism outbreaks may be partly controlled by prompt removal of dead ducks (Eustace 1981), controlling water levels is cheaper and more effective in the long run. Managers generally try to flood lakes to steep, stable banks and to drain the wetland or keep the water level stable to prevent the causes of botulism during summer months (Sperry 1947; Hunter 1970). It is imperative that all managed inland saline wetlands have adequate water level control facilities. Without such control, the wetland may end up killing far more ducks than it produces.

On many freshwater wetlands the manager sometimes has to remove vegetation that is of little value to waterfowl and has grown rank. In the case of highly saline wetlands this is seldom needed as their salt loads often exceed the tolerance limits of undesirable species (like Typha spp.) that may hinder management of freshwater impoundments (Swanson and Meyer 1977).

We have observed numerous muskrats (Ondatra zibethicus) using Montana lakes with 5,000-10,000 mg/L TDS. These animals nearly eliminated all beneficial emergent aquatic plants each year. In these instances, muskrats should be thinned severely. In other rare cases, emergent vegetation in saline wetlands may have to be reduced. At one such area in Oregon, muskrat trapping was regulated so that enough animals survived and kept the vegetation in check (Malheur National Wildl. Refuge 1967). Other methods of controlling emergent aquatic plants including mowing, burning, and herbicide application (Sanderson and Bellrose 1969).

Natural islands in saline lakes are heavily used by duck populations. Because of this there have been projects to build artificial islands (Books 1983). In 1984, Ducks Unlimited made the decision to start improving wetlands south of the Canada - U.S. border. One of their first projects has been to help sponsor construction of islands in Big Lake, Montana (R. Fliger, Montana Dep. Fish Wildl. and Parks, pers. comm. 1985). Such islands can be quite beneficial, as long as they are far enough from shore so that terrestrial predators cannot reach them.

POTENTIAL INLAND SALINE WETLAND MANAGEMENT FOR WATERFOWL

The fact that inland saline wetlands, especially those of less than 1 ha area, may dry up limits their use to waterfowl. At present, such saline potholes are largely ignored by managers, but they might be modified to provide enough permanent water to produce some broods. The cheapest way to improve these wetlands might be to use blasting agents to lower the bottom of the wetland below the permanent water table. This technique has worked well in other types of wetlands (Provost 1948; Franzen 1970; Hopper 1972). A more expensive, but longer-lasting method of creating permanent water in saline potholes is through digging trenches in them with a small dragline. This method has been used successfully on freshwater playa wetlands in Texas (Grubb and Parks 1968).

In coastal marsh management a common management technique is to blend waters of various salinities in impoundments to produce water of a quality most suitable for growth of aquatic plants beneficial to waterfowl (Neely 1962; Chabreck 1967). This concept of water quality control might be applied to inland saline lake management in a variety

of ways. Ducklings (and adults on highly saline lakes) require fresh water. Improving the size of fresh water areas in a saline wetland by diking off fresh water seep areas or incoming fresh water streams would prevent the fresh water from being immediately diluted in the large salt water body. If no fresh springs or streams were available within the wetland, then limited pumping of fresh groundwater into impoundments in or near the wetland might be feasible. As ducks do not need to live on this fresh water but only need to drink a little of it every day, the impoundments could be quite small.

With a reasonably large supply of fresh water available, the manager could blend water in fairly large impoundments to promote growth of aquatic plants. It would be necessary to conduct extensive analysis of the water chemistry and research of compatible plant species before attempting this.

Wetlands may become so saline that higher aquatic plants die off. If there is a salinity gradient in the wetland, pumping or draining the most saline water into evaporation basins may help. Even at high salinities, brines in arid areas will continue to evaporate quite readily (Harbeck 1955), so the basins could handle considerable quantities of water. This management option is being considered at the Bowdoin and Benton Lake National Wildlife Refuges in N. central Montana (G. Sipe and R. Pearson, U.S. Fish and Wildl. Serv., pers. comm. 1985).

Some saline wetlands receive a large part of their water from irrigation return flow (Jensen and Chatin 1964; Madson 1984; G. Sipe and R. Pearson, U.S. Fish and Wildl. Serv., pers. comm. 1985). Used irrigation waters commonly carry large amounts of salts which may aggravate high salinity problems, such as at Bowdoin and Benton Lake. A much more extreme problem, however, occurs at Kesterson National Wildlife Refuge, in California's semi arid San Joaquin Valley. The irrigation water accumulates toxic amounts of selenium which has caused death and deformities in ducklings at the refuge. At Bowdoin, the manager would like to be able to discharge saline refuge waters into a local stream, while at Kesterson, the refuge manager is asking that irrigation be stopped on nearly 17,000 ha of cropland which is returning toxic water to his marsh. Farmers in both areas are opposed. Biologists must check the chemical constituents of irrigation return waters, before establishing saline water management areas that are dependent on such sources.

Many small saline wetlands are quite isolated from major sources of aquatic plants. Visits to such sites indicate that they are species impoverished. A wetlands manager might introduce some promising plant species to these areas, after a complete water analysis has been done for ionic composition. Some estuarine species might be tried. Methods for transplanting beneficial aquatic plants to wetlands have

been well described (McAtee 1939; Harris and Marshall 1960; Kadlec and Wentz 1974; Rutherford and Snyder 1983).

In western North America, livestock grazing is an important business. Saline lakes often are located in grassland areas because poor soils, or saline seeps, prevent the establishment of cropland. Wildlife agencies might wish to consider funding ranchers to fence off saline wetlands. Fences would keep cattle from trampling waterfowl nests near the shore, and would keep the cattle from miring down in sticky soils that often border saline wetlands.

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INDUSTRIAL EXPERIENCE WITH PRAIRIE WATERS

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ABSTRACT

Industrial use of prairie water can be affected by its low quality or by shortage. Potential problems and the solutions are discussed for uses involving zero discharge to full return systems.

INTRODUCTION

With the province's relatively low population and its massive commitment to agriculture, it could be assumed that demands by industry on the surface waters of southern Saskatchewan might be quite light. This is, in fact, a reasonable assumption of the general situation but southern Saskatchewan has a representative, if small, cross-section of industrial user types (Table 1).

TABLE 1: 1983 Industrial production in Saskatchewan as millions of dollars (Saskatchewan Economic Development and Trade)

Agriculture	$ 2,049
Forestry	37
Mining	1,375
Construction	824
Manufacturing	971
Transportation, Communications & Storage	1,175
Utilities	362
Trade	1,572
Finance, Insurance & Real Estate	2,106
Services	2,679
Public Administration	1,700
Gross Domestic Product at Factor Cost	$14,849

Very often their need for water is modified by the quality and quantity of water available. Thus, in many cases, a good deal of ingenuity is required to ensure that an inferior quality and quantity of water will be sufficient to meet their needs.

Two terms are used extensively in this paper, with respect to water use. These are:

Consumptive Use	The removal of water from a source with no direct return after use
Non-Consumptive Use	The removal of water from a source with direct return after use.

Use of water by an industrial plant is rarely, if ever, accomplished without some change in the quality of that water. For example, a plant using water for cooling may return all of the water, but that water will have acquired a higher temperature. Similarly, water used to power hydraulic turbines will normally be subtly different at the tail race of the turbine from its original state in the head pond, where it was usually under some considerably higher pressure. A foundry washing castings and clarifying the water before its return to the source still adds something to the water. Thus, non-consumptive use is rarely without some change to the downstream quality.

There are many definitions of the "ideal" use of water by an industry, but the one following appears to be reasonable regarding both the industrial and environmental necessities of water use in the generally arid prairie regions. Ideal use of water should ensure that consumptive use removes only such a proportion of the water body that downstream users' needs are still adequately met. All use should ensure that the change in nature of the water should be such that the main body can easily assimilate the changes in a reasonable contact time so that the water body is acceptable for the next user or its natural inhabitants.

When water is unavailable in quantities sufficient to satisfy all municipal, agricultural, recreational, and industrial needs, some planning and control may be required. When water quality is poor, there is a far greater need for ingenuity on the part of all users. In the extreme, many potential users may even have to avoid the use of the surface water or to pretreat it, depending on the quality requirements of the intended use. Many of the surface waters in southern Saskatchewan present such a challenge. Often, the choice of location of an industry will involve not only the question of whether there is sufficient water for the required industry but also whether the quality is economically useable.

NON-CONSUMPTIVE USE PROBLEMS

By far the most common non-consumptive use of water is for cooling. The coolers or condensers which provide this service, unless extremely overdesigned, are usually quite sensitive to reduction in flow of water through the tubes or flow of heat through the tube metal.

1. Silt

In some designs, silt may plug heat exchangers, reducing flow and, hence, affecting the ability of the device to cool the process. Silt may also settle and accumulate on the lower surfaces of horizontal tubes. Increased velocity, with a penalty of increased pumping costs, can keep the silt in motion and thus reduce the problem. There

is, however, a limit to this solution even assuming that the cooler can handle the extra pressures and velocities involved. Above a certain velocity, depending on the extent of abrasiveness of the silt particles, erosion of the tube surface can be expected. Erosion leads to premature failure of the process when it is contaminated by cooling water which has escaped from damaged tubes (Figures 1 and 2).

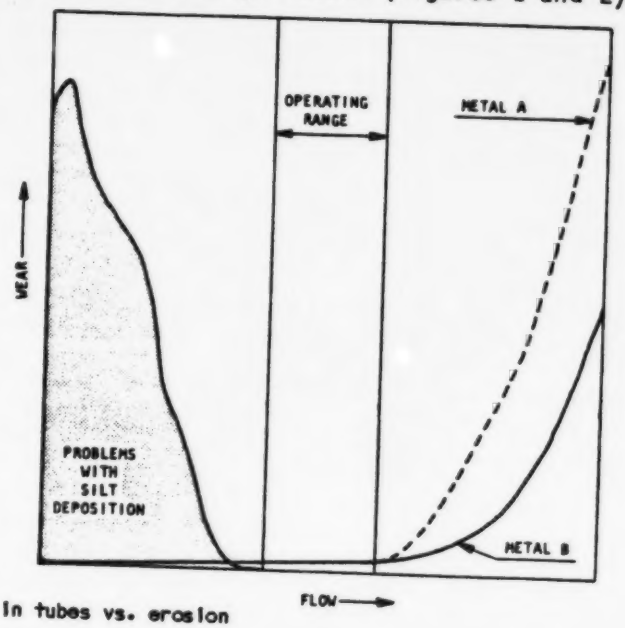


Figure 1. Flow rates in tubes vs. erosion

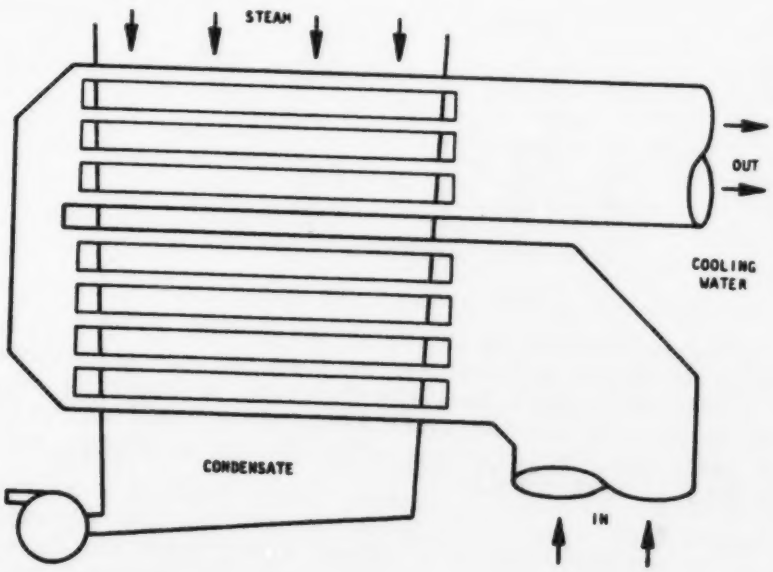


Figure 2. Typical cooling device

2. Scales

Various scaling indices predict the nature of the water in southern Saskatchewan in terms of either scaling or corrosive tendency (Table 2). Most Saskatchewan waters will be found in either the safe or mildly scaling areas of this system (Table 3).

TABLE 2: A comparison of the Langelier and Ryznar scaling indices

Langelier	-3 ←	0 →	+3
Ryznar	10 ←	6 →	3

Increased scale solubility ← stable → Increased scaling

TABLE 3: Scaling index data for two Saskatchewan thermal cooling reservoirs (Saskatchewan Power Corp. unpublished data)

Month	Cookson Reservoir		Boundary Reservoir	
	Ryznar	Langelier	Ryznar	Langelier
1983				
January	5.0	1.8	5.85	1.89
February	4.89	1.87	5.86	1.17
March	4.88	1.87	5.85	1.19
April	4.89	1.86	5.86	1.20
May	4.87	1.87	5.97	1.10
June	4.92	1.84	6.00	1.10
July	4.82	1.91	5.95	1.13
August	4.89	1.87	5.87	1.18
September	4.84	1.90	5.79	1.23
October	4.78	1.93	5.72	1.27
November	4.73	1.95	5.54	1.38
December	4.58	2.05	5.55	1.37
1984				
January	4.57	2.06	5.53	1.35
February	4.69	1.96	5.52	1.35
March	4.60	2.01	5.54	1.35
April	4.74	1.93	5.56	1.33
May	4.65	1.97	5.54	1.34

Alkaline waters with relatively high calcium content produce scaling if water temperature or chemical concentrations are raised. Since heat exchangers have the function of reducing process temperatures by raising cooling water temperature, scaling, usually with calcium carbonate, on occasions with calcium sulphate, can be a problem in plants in Saskatchewan.

3. Organic Slimes

If the environment within the tube of a cooler is hospitable, nature will inevitably try to take over. In many cases, the added warmth of the heat exchanger tube will greatly enhance the rate of production of organic material, resulting in slimes or coatings which, although less mechanically strong than carbonate scales, are still able to restrict heat transfer sufficiently to upset most processes. When coolers are used only intermittently, or stand stagnant between operating periods, organic slimes require special treatment either at standby or at restarts before the process can be effective. Tubes containing copper resist organic growth and adhesion better than stainless steel tubes.

4. Chemical Attack

The suitability of cooling water depends also on its chemical quality. The types of materials chosen for chiller or cooler tubes, the presence of oxygen, the pH of the water and the chloride content can all have a serious effect on the service life of the equipment and its efficiency while in service (Table 4). Tube materials are usually copper alloys -- either copper/nickel or copper/zinc -- and by their nature they have some resistance to oxygen and reasonable service life at high pHs. The use of stainless steel coolant tubes is often required in the food industry, however, and these tubes are sometimes less able to withstand the ravages of unsuitable cooling water. Highly saline water may be expected to put a lower grade stainless steel tube at risk in a highly stressed application.

TABLE 4: Tube Metal Properties in Fresh/Brackish Water

Materials	Resistance to problems		
	Biofouling	Silt/Erosion	High Salinity
Brass	resistent	susceptible	good
Cupro-Nickel	resistent	less susceptible	good
Stainless Steel	susceptible	resistent	inconsistent
Titanium	susceptible	resistent	good

It may be necessary to change the process and/or the equipment to get good use from a water source.

CONSUMPTIVE USE PROBLEMS

Quality is generally more critical when the water is to be used as an ingredient in a process rather than as a coolant. Water treatment will depend on the quality of water required. In consumptive use, the nature of the water needs changing, rather than modifying the process as in non-consumptive uses.

1. Suspended Solids

Perfectly clear water, or water of some pre-determined clarity, is required for many consumptive processes. Using water of lesser quality than specified can result in plugged or seized mechanical components, plugged control lines or orifices, difficulties in maintaining correct flows and controls over a long period and inefficiency of processes, such as ion exchange.

2. Colloids

Failure to consider the less obvious problem of colloidal matter in water has been the downfall of many industrial processes. The choice of a process to reduce colloidal matter, usually at the same stage as reduction of suspended or dissolved solids, is useful. The failure to remove colloids in the process can result in their appearance at an embarrassing point later in the system. A good example is silica which, in the unionized form, can remain undetected until the process water is heated. At this stage the point may have been passed where silica would normally be removed and, thus, it becomes an expensive nuisance inhibiting the efficiency of the process.

3. Salinity

Some industries employ processes which require water of very specific quality, quite unlike the quality of the water from sources located nearby. The transistor industry is known to need an extremely high purity de-ionized water often referred to as "conductivity water." The electric utility industry requires water only slightly less refined. The food industry and the beverage industry each have standards for many of the inorganic and organic constituents. Many other industries require a water which does not scale or react with the process. This means that all or some specific ions must be removed from the water. On a more mundane level, the weekly laundry requires soft water and only small amounts of iron or manganese can be allowed in the water if clothes are to be properly washed.

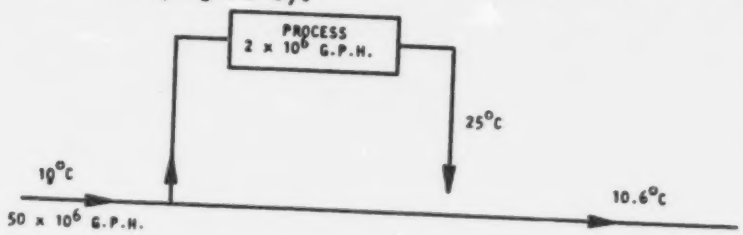
When an industrial plant is being designed, careful consideration must be given to the water quality requirements of its various processes, since the local raw water supply may not permit successful use of standard equipment. Even the design of commonplace items, such as coolers, chillers and clarifiers, needs to be examined with reference to the problems of quality of the local raw water.

SOLUTIONS AVAILABLE TO INDUSTRY

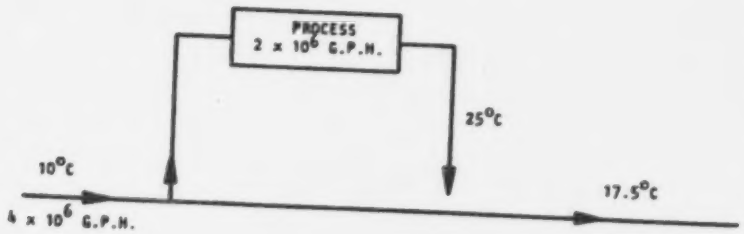
One of the first choices which must be made with reference to the use of surface water as a coolant is whether the body providing the

water has sufficient volumetric resources to allow for environmentally acceptable discharge of heated effluents, assuming that no other changes have been made. Where this is not the case, industry must very often choose the less economical alternative of extraction of water and the use of a "closed" cooling system. The extent of these changes from the "once through" to a closed, continuous cooling, system are not always realized and should be examined further.

By definition, non-consumptive cooling makes only minor chemical changes, plus additional heat, when the water used as coolant is discharged. The cooling requirement for small rivers would often be a large proportion of the river's flow. Significant, environmentally unacceptable changes to the river conditions would be made downstream. Where this may be the case, a choice must be made between air cooling or consumptive use of water for a closed system, which returns no water to the river (Figure 3).



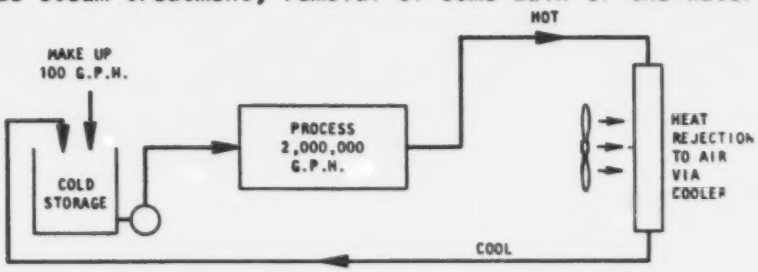
PROCESS ON LARGE WATER BODY



PROCESS ON SMALL WATER BODY

Figure 3. Effect of size of receiving water body on non consumptive cooling use

Generally, the differences between a closed and open system can be listed as follows. When the closed system is used for cooling, it must then itself be cooled in some other stage in the process prior to being re-used. This cooling can be achieved either with a system where the heat is transferred to air or to some other medium by conduction -- much like the cooling system of the automobile (Figure 4) -- or the heat can be rejected by an evaporative cooling tower. Although usually more expensive, the conductive, non-evaporative system requires little make-up, can be chemically treated once, and usually requires little attention other than that leakage losses are made up with good quality water. By comparison, the closed cooling system, using evaporation for heat rejection, loses some proportion of its water at each cooling cycle and the salinity of the water is increased to a point where treatment is required. This treatment takes the form of <u>in situ</u> or side steam treatment, removal of some bulk of the water,



CONDUCTIVE HEAT REJECTION

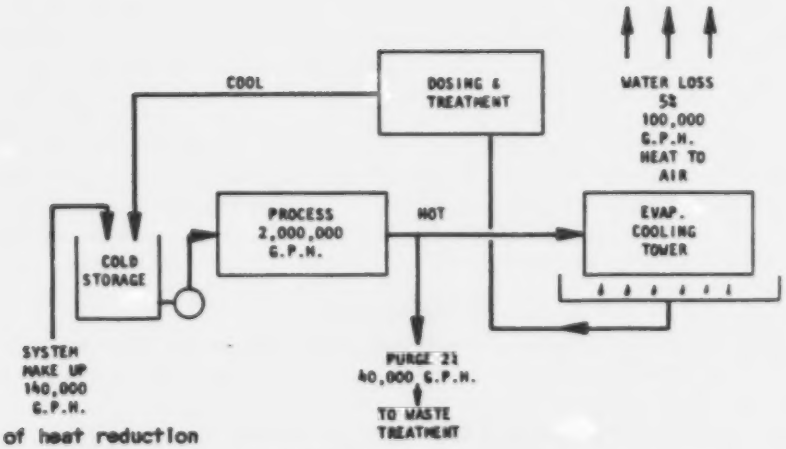


Figure 4. Types of heat reduction

EVAPORATIVE HEAT REJECTION

and replacement with fresh make-up water. It is easier to prevent corrosion, biological fouling, and calcium scale occurrence in a closed system than in a once through system. This is a good example of water scarcity imposing economic and environmental restraints on the design of a system. It also implies the need for a higher class of chemical treatment in the operation of a closed system.

Another increasingly used technique is the so-called zero discharge system. This is usually an environmentally imposed scheme which prevents chemically damaging effluent being returned to the source. All in-plant wastes are utilized in a process that requires lower quality water on a descending order of use (See Figure 5). The result is the treatment or destruction of all effluents. This is often a more economic measure than expensive treatment of effluents prior to discharge.

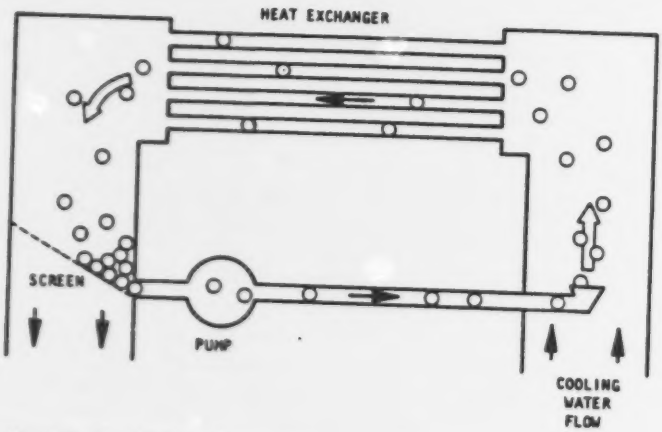


Figure 5. Mechanical tube cleaning

TREATMENTS USED BY INDUSTRY

1. Calcium Scale

Whether the system is a once through cooling system running on bad water or a closed evaporative system which by evaporation has produced a similar quality, calcium scale is inevitable when certain solubility limits are exceeded. Industry has numerous treatment choices from pH reduction by acid addition (which usually has penalties with respect to the inhibition of the system) to the addition of modifying chemicals. The modifying chemicals cause the calcium to be precipitated as a sludge or held in suspension rather than plated out as a heat-insulating scale. Table 5 indicates some of the currently available chemicals and their abilities.

TABLE 5: Chemicals for Calcium Scale Control

1. Maintain scale-former in a soluble form.
- Acids
- Polyphosphates
- Phosphonates and Phosphate Esters
2. Modify crystal form and so prevent a scale buildup.
- Polyacrylates
- Polymaleics
- Sulphonated polystyrene
- Phosphates

The most environmentally acceptable method for scale, slime and silt control is the mechanical on-line method (Figure 6).

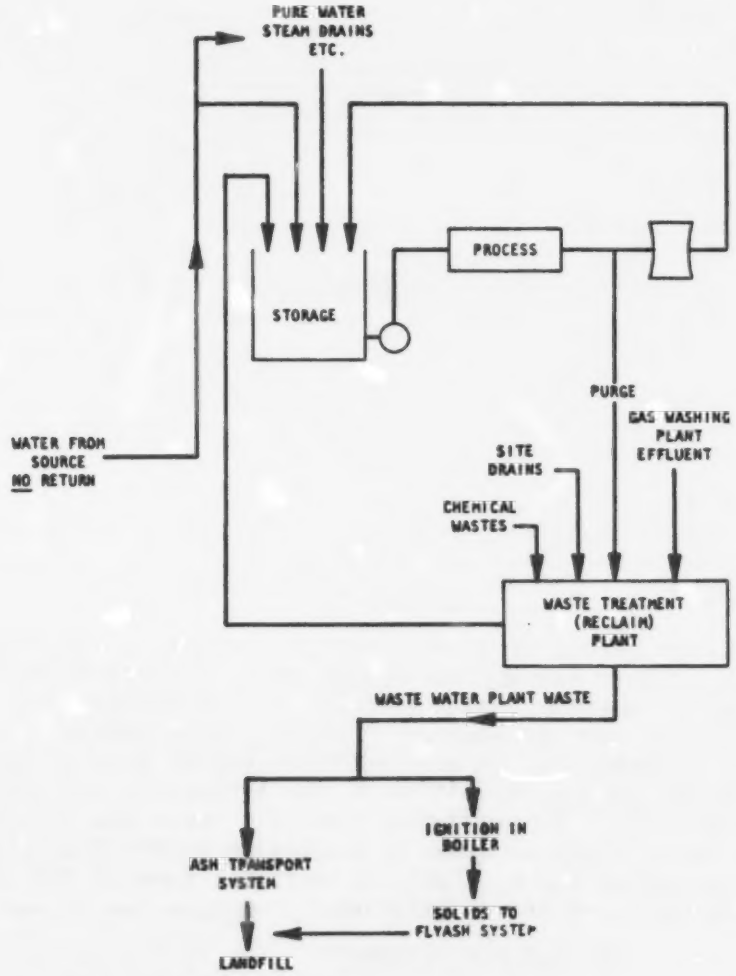


Figure 6. Typical zero discharge system

2. Biological Fouling

The warm condition of condenser or cooler tubes, with periodic slow water flows, form ideal environments for rapid growth of various biological species from the parent water. In many cases, these grow in different proportions at the new, higher temperature compared with the populations in the parent water body. In general, preventing the growth of this organic slime is more satisfactory than shutting down to remove it mechanically. Prevention can normally be achieved by the addition of chemicals. In a closed system, these can be chemicals as diverse as organo-sulphur compounds, bromine organics, copper salts, quaternary ammonium salts, or chlorine gas. In an open (once through) system only the more gentle of these, which have a very short active life, can be used. In the use of chlorine, although conditions can be organized so that there is no residual of free chlorine at the station discharge, the highly organic state of most surface waters increases the possibility that trihalomethanes will form in the cooling water. For this reason chlorination is used as infrequently as possible. In recent years a promising alternative to chlorination has been the use of brominated propionamides. Although these are potent biocides they are important because their half life is considerably shortened with rising pH and temperature. It is possible to manipulate plant conditions to reduce the concentration of these chemicals before the cooling water reaches the open environment.

3. Corrosion

In a once through system operators can do little with respect to corrosion, although the designers can ensure that metals chosen have a resistance to the conditions of the cooling water. Brass and stainless steel components operate quite well using prairie waters, even when there is little chemical treatment to prevent corrosion. In a closed system, where water may be recirculated as many as twenty times, it is necessary to treat the system to prevent corrosion. The technology of corrosion prevention by the use of anionic or cationic inhibitors is a complex subject and will not be treated here. Anti-corrosion treatments must, however, be balanced with those to reduce scaling and to prevent biological fouling in the system.

WATER PURIFICATION

The properties of water for cooling are one major consideration, however, many industries require water as an ingredient in a process and the quality of the water therefore becomes important. It has already been suggested that a plant's design should be modified to allow compromise with local surface water quality. Where the water is used as an ingredient the reverse is normally true. This is certainly the case with municipal drinking water plants where the quality of water

must meet certain standards of clarity, sterility, and often hardness as well as freedom from certain trace elements. Compared with these municipal objectives industrial requirements are often more sophisticated. Industrial requirements range from water similar to municipal water supplies where clarification, colloid removal, or softening may be needed, to fully demineralized water or the even higher quality demineralized water required by the semi-conductor industry.

To produce these types of water all, or some, of the following devices are used, usually with success (Figure 7). Prairie water often contains a considerable amount of colloidal matter, so simple

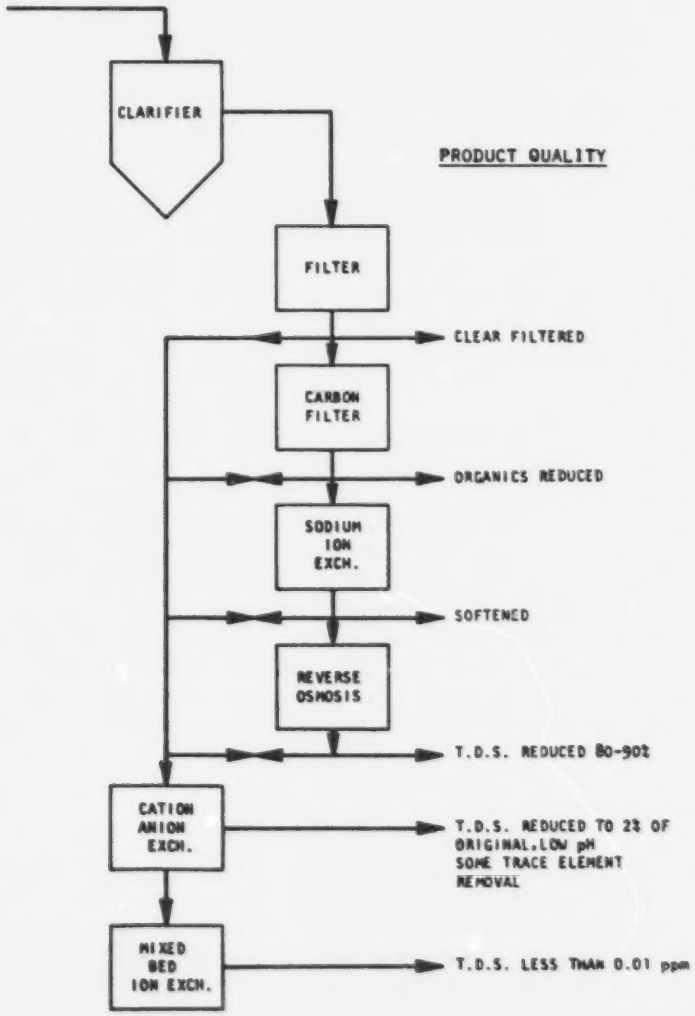


Figure 7. Typical water treatment devices

filtration is usually ineffective unless certain pretreatment chemicals have been employed. The use of a clarifier prior to filtration is the normal mode. Sometimes, where softening is required, this clarifier operates on a regime which is alkaline and contains an excess of hydrated lime, thus removing calcium carbonate and other calcium salts, by precipitation. Alternatively, it is run on an alum regime where no softening is obtained, but good removal of fine sediment and colloids can be achieved prior to filtration. For many purposes, a clarified water is a good feed for the system or for later treatment. Treatment will often include the removal of iron or full demineralization for other more demanding requirements.

Prairie surface water salinities are often such that ion exchange would not be economic. It has been found that prior treatment by reverse osmosis will reduce the salinity levels at a reasonable cost so that chemical costs of demineralization are acceptable. Such is the case at all of the larger power plants which require high purity water.

DISCUSSION

Southern Saskatchewan's surface waters are such that industry cannot assume the availability of cooling water. Often a site must be chosen where there must be modifications to the water supply to ensure its availability in the required quantity and quality. This may involve pipelining or siting the plant near to an available water source, even though this may not be the best point for some other economical reason, such as rail access or the availability of raw materials.

Having found a water source, the plant design should be modified to meet the demands of the water's characteristics. This is usually a compromise and, for most consulting companies, it is a relatively easy task. The design of components within the system, however, is not always considered as deeply as may be necessary. Some tube materials in a cooler will work adequately in aerated sea water but will corrode when the oxygen has been removed, as happens in some estuaries below large cities. Similarly, some tube materials will work well in fresh water, but will work less well in highly saline water. The choice of construction materials therefore becomes highly specialized and must relate to users' previous experience with that type of water. Again, water problems which are not even considered by industries around the Great Lakes, are commonplace in prairie regions and a manufacturer who does not realize these great differences may specify incorrect models or trim, when valves, coolers, and other items are supplied from catalogues.

Even when the correct types of materials are used in plant construction, the operation will still require some employees with chemical skills in order to use the water wisely, to remain a good environmental neighbour.

In the prairies, a water supply is rarely unlimited, and problem effluents may be little diluted by the receiving water. This contrasts with coastal plant operations, and those operating on the Great Lakes, where effluents are greatly diluted. Some of the more highly developed biocides and corrosion inhibitors are unacceptable since they would affect the receiving water. One advantage of the closed cycle, extractive, zero-discharge method of cooling is that water with unacceptable quality for the cooling system can be used in less demanding areas. The water may be used to moisten ash before its disposal in landfill, or as a liquor for flue gas scrubbers. The reuse of water reduces the quantities released to the receiving environment.

CONCLUSION

In general, prairie industries have learned to cope with water of low quality and insufficient quantity. The problem of quality has been resolved in many cases by more expensive plant construction and higher quality components. The greater use of chemicals has also aided in overcoming the problem, although discharge requirements have sometimes precluded their most efficient use. Industries, some of them quite dissimilar, have had to learn to cooperate with one another in regard to upstream and downstream use of the water supply.

Industrial demands on prairie water supplies are likely to increase in the future, so that the proportion per user of the available water supply may decline. Thus, industry will face an even greater challenge, doing better with less water, or doing the job without any water.

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RECREATION POTENTIAL OF SALINE LAKES IN SASKATCHEWAN

Alan G. Appleby and Roger Green

ABSTRACT

Forty saline lakes in Saskatchewan were surveyed for physical and chemical characteristics which would affect water-based recreation. Saline lakes in Saskatchewan have many limitations for recreational use and development, but salinity, per se, is not a major factor. In spite of the limitations, a surprising amount of recreation of various types occurs at smaller and deeper saline lakes throughout the southern parts of the province. Over 300,000 visitors enjoyed recreational experiences at 12 regional parks based on saline lakes in 1984 alone. With few exceptions, the recreational aspects of the saline lakes involved are primarily of local or regional significance; however, the extensive nature of the recreational developments to date, the public acceptance of recreation in such environment, and the number of saline lakes with recreational potential, suggest that further developments will occur.

SALINE LAKE RECREATION AROUND THE WORLD

Saline lakes are widely distributed throughout the world (Hammer 1978), but there is little literature available related to their recreational use (I.E.C. Beak Consultants Ltd. 1984), and considerable research is required to develop an accurate understanding of saline lake-based recreation. Nonetheless, it is known that recreational use of saline lakes does occur in some parts of the world. Angling, boating and swimming occur at a few of the many saline lakes in Australia (Hammer 1981). Some African saline lakes are known to be popular for viewing wildlife, especially unique birds such as flamingos (I.E.C. Beak Consultants Ltd. 1984). Richard Leakey, in his autobiography, describes leading a group of photographers to one such lake although the presence of lions severely hampered the photographic opportunities (Leakey 1984). Throughout Europe and Asia saline lakes are often associated with health resorts and spas, and curative properties are attributed to drinking the water as well as bathing in it (I.E.C. Beak Consultants Ltd. 1984). In eastern Europe, saline mud baths are also considered to be therapeutic (Zhadim & Gerd 1961). The popularity of Ibusuki, a major resort city in southern Japan, is based in part on saline sand baths and spa waters (Ibusuki Tourist Association 1984). Virtually nothing is known of the recreational uses of the large number of saline lakes in various locations throughout South America (I.E.C. Beak Consultants Ltd. 1984). It is difficult to ima-

gine any recreation use at all occurring at the saline lakes in Antarctica. In North America, saline lakes are located in the western United States and western Canada. Several of the American lakes are well known, including Salton Sea in southern California, Pyramid Lake in Nevada and, of course, Great Salt Lake in Utah. Salton Sea supports several recreation activities including angling and waterfowl hunting as well as wildlife observation and photography, biking, hiking and horseback riding. The area features a large national wildlife refuge and mineral spas are located nearby. Pyramid Lake supports an active commercial and sport fishery in northwestern Nevada (I.E.C. Beak Consultants Ltd. 1984).

Great Salt Lake, in Utah, is the best known saline lake in North America. It has a long history of recreation use with several resorts being established in the 1880s and 1890s. Receding lake levels led to the abandonment of most of the resorts by the mid 1960s, when only the Silver Sands Resort remained in operation. A 2,000 acre state park was developed on Antelope Island during the 1960s and recreational interest revived during the 1970s. Today at least 2 million visitors per year enjoy a variety of recreational activities including boating, swimming, camping and picnicking. In addition, the marshes associated with Great Salt Lake are the single most important waterfowl hunting area in Utah (I.E.C. Beak Consultants Ltd. 1984).

In Canada, the majority of saline lakes are located in southern Saskatchewan and Alberta (Hammer 1978). Several saline lakes in Alberta are utilized to some degree for boating, angling and swimming. Miguelon Lake, in the Miguelon Lake Provincial Park, northwest of Camrose, is well known as a staging area for migrating waterfowl, pelicans, and great blue herons. Camping and a limited range of recreational activities, such as hiking and swimming, are accommodated in the park (I.E.C. Beak Consultants Ltd. 1984).

SALINE LAKES IN SASKATCHEWAN

Saline lakes in Saskatchewan are scattered throughout the prairie and parkland areas of the province, although they are more common in the prairie region (Hammer et al. 1975). They vary from small temporary water bodies to large permanent lakes; Big Quill Lake, near Wynyard, is the largest saline lake in Canada, although it is quite shallow. Figure 1 shows the location of the 40 inventoried lakes.

No recreation-based definition or classification system has been devised for saline lakes. The widely accepted minimum of 3 g/L total dissolved solids (Williams 1964) was used to define the 40 saline lakes inventoried for this paper. Although it is not based on recreation parameters, the definition appears to be reasonable for use in formulating plans for recreational facilities. Wakaw Lake, for in-

stance, has a salinity of 3.48 g/L (I.E.C. Beak Consultants Ltd. 1984). Casual users, including swimmers, are generally not aware that the lake is saline, but concerns have been raised about the implications of using lake water for golf course irrigation (G. Baudais, Wakaw Lake Regional Park Board, pers. comm. 1985).

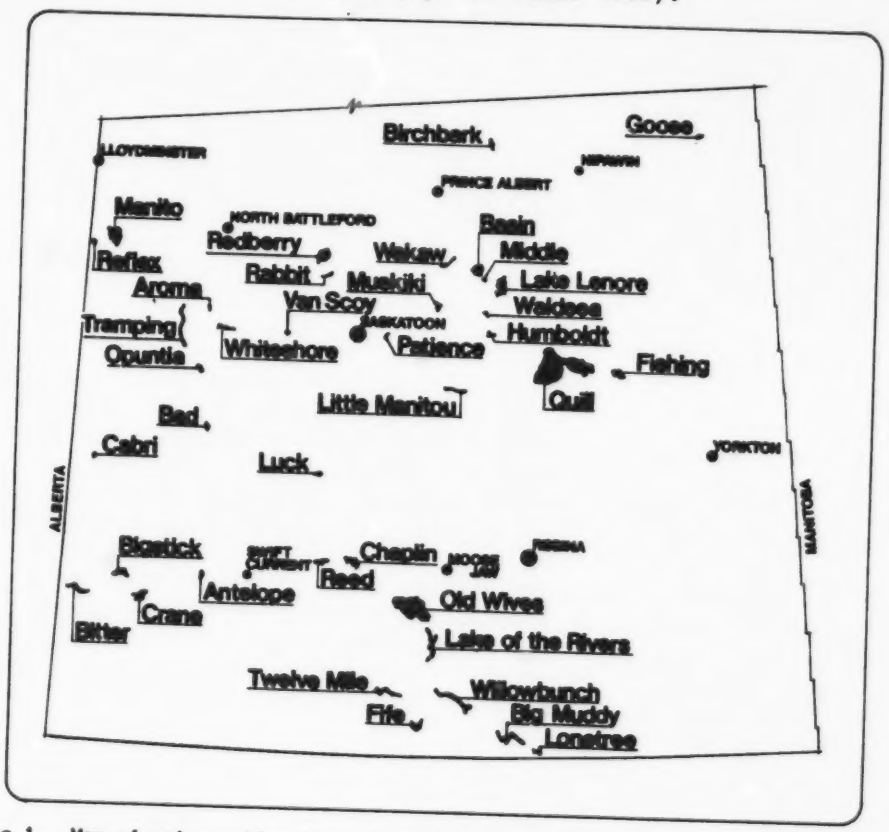


Figure 1. Map of major saline lakes in Saskatchewan

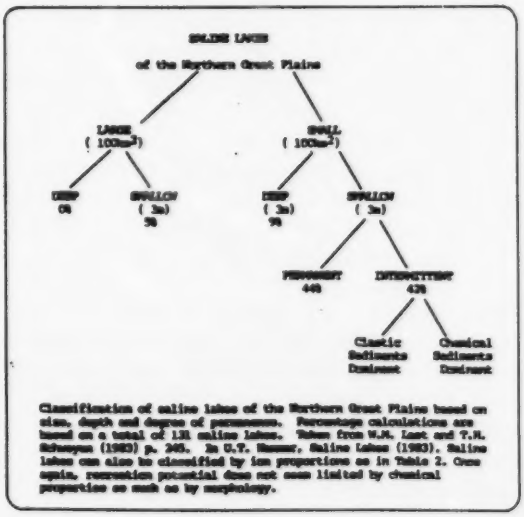
Several classification systems based on a variety of criteria have been developed for saline lakes. The general classification, based on the degree of salinity (Beadle 1959, Hammer 1983), appears to be useful from a recreation perspective. Table 1 classifies the 40 lakes inventoried in this study accordingly.

Recreation development in Saskatchewan occurs to varying degrees at lakes within each classification, although the majority of development has been at hyposaline lakes. In addition, the hyposaline range bears at least some relationship to fish survival. Angling success is one of the important factors in assessing the recreational potential of lakes.

TABLE 1: Classification of 40 Saskatchewan Lakes by Salinity
(Numbers in brackets indicate salinity in g/L)

SUBSALINE Less than 3 g/L		HYPOSALINE 3-20 g/L		MESOSALINE 20-50 g/L		HYPERSALINE More than 50 g/L	
Crane	(2.2)	Birchbark	(3.3)	Waldsea	(22.9)	Little Manitou	(81.4)
Fife	(2.6)	Lake of Rivers	(3.5)	Middle	(24.6)	Aroma	(85.2)
		Wakaw	(3.5)	Manito	(25.2)	Chaplin East	(107.7)
		Big Muddy	(3.9)	Goose	(27.7)	Bitter	(109.1)
		Humboldt	(3.9)	Willowbunch	(30.5)	Whiteshore	(201.2)
		Reed	(4.0)	Big Quill	(47.5)	Patience	(207.2)
		Twelve Mile	(4.2)			Chaplin West	(213.7)
		Fishing	(4.3)			Muskiki	(342.1)
		Old Wives	(4.4)				
		Luck	(4.7)				
		Cabri	(4.8)				
		Bad	(5.1)				
		Chaplin South	(5.9)				
		Lake Lenore	(6.4)				
		Antelope	(7.6)				
		Reflex	(8.0)				
		Rabbit	(8.2)				
		Tramping	(8.5)				
		Opuntia	(?)				
		Lonetree	(9.7)				
		Van Scoy	(12.3)				
		Basin	(17.6)				
		Redberry	(19.4)				

Some interesting observations may also be drawn from the classification scheme for Saline Lakes of the Great Plains based on basin morphology, as identified by Last and Schweyen (1983). This system takes into account lake size, depth and degree of permanence. Figure 2 illustrates the classification. From a recreational perspective this classification indicates:



Classification of saline lakes of the Northern Great Plains based on size, depth and degree of permanence. Percentage calculations are based on a total of 131 saline lakes. Taken from W.M. Last and T.M. Schweyen (1983) p. 245. In G.T. Nesser, Saline Lakes (1983). Saline lakes can also be classified by ion proportions as in Table 2. Once again, recreation potential does not seem limited by chemical properties as much as by morphology.

Figure 2. Classification of saline lakes on the northern Great Plains

1. All of the large (>100 km^2) saline lakes have maximum depths of less than 3 m, and are likely too shallow to support consistent and varied active recreation activities

2. Of small lakes (<100 km^2), only 9% are greater than 3 m in maximum depth, and therefore likely to support active recreation activities

3. Furthermore, of the shallow small lakes, only 44% are permanent waterbodies which would lend themselves to some consistent recreational experience

4. The bulk of recreational activity is likely to be centred on the 9% of lakes which are small (<100 km^2) and deep (>3 m).

These conclusions are borne out by the information collected on saline lakes currently supporting recreational developments.

RECREATION POTENTIAL - LIMITING FACTORS

The recreation potential of a lake is determined through the interaction of a wide variety of highly variable factors. Such factors may be physical, cultural, or attitudinal. Physical factors include the chemical and biophysical characteristics of the lake as well as the soils, topography, vegetation and other natural features of the adjacent shoreland. Cultural factors often involve such things as land use and ownership, ease of access, and a wide range of economic and other considerations. Attitudinal factors, relating to the perceived suitability of a lake to provide an appropriate setting for various recreation activities, include past experience and aesthetic considerations.

A wide array of recreation activities are commonly associated with saline lakes. Traditionally, the recreation appeal of a lake is most often based on the key water-oriented activities of angling and swimming. Other water based activities, such as waterskiing, pleasure boating, canoeing and sailing occur in conjunction with swimming and angling. Shoreland recreation, such as picnicking, camping and cottaging usually occurs adjacent to lakes which provide good angling and swimming opportunities.

Many factors limit the recreation potential of the saline lakes in Saskatchewan. Angling is discussed by Atton in this symposium. As noted, however, the presence of a viable sports fishery is an incentive to other recreation development.

In terms of swimming, salinity is not a major limitation. The guidelines for Canadian Recreation Water Quality do not establish a maximum salinity for water contact recreation. There are, however, criteria for acceptable water pH values. The pH level should be between 5.0 and 9.0 for water contact recreation. Values in excess of 9.0 are reported to cause eye irritation (I.E.C. Beak 1984). Several saline lakes in Saskatchewan have pH values greater than 9.0 and three of them -- Redberry, Manito, and Fife Lakes -- have beach areas for swimming.

Swimming is a very popular activity at Redberry Lake and many swimmers, especially children, spend a great deal of time in the water (E. Boyko, Redberry L. Regional Park Board, pers. comm. 1985). In spite of a pH value of 9.2 (Fournier, Redberry L. Regional Parks Board, pers. comm. 1985), swimmers do not complain of eye irritation, although occasional complaints of irritated nasal passages are reported.

Swimming in Redberry Lake does result in salt deposits forming on skin, but there have been no complaints of rashes or other irritations as a result. The problem seems to be adequately resolved by providing a fresh water shower at the beach (E. Boyko, Redberry L. Regional Park, pers. comm. 1985). Care should be taken to avoid swallowing water in Redberry Lake. The water has been compared to a 7% solution of Epsom Salts and is reported to perform very well as a fast and effective laxative (W. Gumprich, Saskatoon Sailing Club, pers. comm. 1985).

On a positive note, the extra buoyancy of saline water enhances its attraction for swimming. In addition to the novelty, the buoyancy gives beginners and people with limited ability extra confidence. The extra buoyancy at Redberry Lake is apparently at least part of the reason for the popularity of swimming lessons given at the lake (E. Boyko, Redberry L. Regional Park Board, pers. comm. 1985).

Other water quality criteria which affect the suitability of lakes for swimming include water clarity and the presence of algae (Parkes 1973). The Guidelines for Canadian Recreation Water Quality suggest water should be sufficiently clear to read a secchi disc at a depth of 1.2 m. Clarity among saline lakes in Saskatchewan is highly variable, ranging from as little as 10 cm at Old Wives Lake to in excess of 10 m at Redberry Lake (Hammer 1975). Algae are a widespread problem in many lakes in southern Saskatchewan. Late summer algae blooms are reported to cause skin irritation and otherwise reduce the recreational potential at several saline lakes, including Lake Lenore (D. Hawes, St. Brieux Regional Park Board, pers. comm. 1985), Wakaw Lake (Baudais, pers. comm. 1985) and a number of others.

The degree of salinity no longer poses major limitations for boating or sailing. At one time, boats and motors commonly suffered from corrosion in saline waters, but the widespread use of fibreglass and corrosion-proof metals have greatly reduced this problem. Nonetheless, boaters at Redberry Lake have reported some damage to boat paint and other finishes if vessels remain in the lake for prolonged periods (E. Boyko, Redberry Lake Regional Park Board, pers. comm. 1985); there is also an "irritation factor" related to salt deposits fouling outboard motor ports and the general requirement for extra cleaning to keep boats, fittings, sails and other equipment in good condition (W. Gumprich, Saskatoon Sailing Club, pers. comm. 1985).

Swimming and boating are severely limited by shallow water at many of the saline lakes in the province. Old Wives, Twelve Mile, Willowbunch and several other lakes have a maximum depth of 1 m or less (I.E.C. Beak Consultants Ltd. 1984). The recreational appeal of many saline lakes is further reduced by extensive fluctuations in water levels from year to year, as well as seasonally. The extensive mud flats and sedimentary bottom muck, characteristic of many saline lakes, do little to encourage water-contact recreation.

Shoreland recreations, such as picnicking, camping and cottaging, are not directly limited by the degree of salinity, although these activities may be limited indirectly by the ability of a lake to support desirable associated water-based recreation, such as swimming and fishing. Other important considerations include the aesthetics of the lake and shoreland; many saline lakes in Saskatchewan are located in sparsely treed landscapes of low relief which have limited recreational appeal.

SALINE LAKE-BASED RECREATION IN SASKATCHEWAN

Outdoor recreation includes a wide spectrum of leisure-time activities with varying degrees of local intensity and impact which require corresponding levels of facility development and infrastructure. This continuum may be represented as extending from a solitary wilderness experience to that of a full service four season destination resort. Saline lakes in Saskatchewan, in spite of their many limitations, provide a wide range of opportunities extending across nearly the full spectrum of recreational activities.

Two general categories of recreation commonly associated with fisheries and wildlife are often characterized as being either consumptive or non-consumptive. Consumptive recreation includes hunting and fishing, while non-consumptive recreation includes such activities as wildlife observation and photography. Recreational fishing is discussed by Atton, "Fish in Endorheic Systems and Saline Waters," in this symposium.

Although the recreational values characteristic of consumptive and non-consumptive users are often in conflict, opportunities for co-operation do exist. The Saskatchewan Heritage Marsh Program is a good example of a positive relationship between the two categories of recreation. Construction began on the third Heritage Marsh project at the south end of Chaplin Lake in 1984. There, prime waterfowl breeding area is being developed under an agreement between the Saskatchewan Government, Ducks Unlimited Canada, the Saskatchewan Wildlife Federation, and the Saskatchewan Natural History Society. The waterfowl project, in conjunction with large shorebird populations, the sodium sulphate solution mining process, and the brine shrimp fishery, provides an excellent opportunity for interpretive development in close proximity to the Trans Canada Highway.

Hunting and wildlife observation are extensive activities requiring little in the way of development. A few saline lakes in the province represent the other end of the recreation spectrum. Little Manitou Lake, near Watrous, has had a long history of intensive recreational development. "The Golden Age of Manitou Beach" extended from 1910 to the early 1950s (Baker 1965). The curative and therapeutic properties of the lake were widely promoted during those years, and cottages, hotels, dance pavilions, bath houses, swimming pools and a wide variety of other recreational establishments thrived (Lozinsky 1979). The resort has declined considerably since its heyday in the 1930s, although a 1982 preliminary feasibility study indicated that the unique mineral composition and density of the lake remain attractive to a specific purpose resort development.

A surprising numer of saline lakes in Saskatchewan provide a variety of family recreation opportunities within the mid-range of the recreational spectrum. Most significant of these moderate developments are Regional Parks. Of the 40 saline lakes inventoried for this paper, 12 have Regional Parks associated with them. These are summarized in Table 2.

All four salinity classifications are represented among these lakes, although the majority of lakes (8) are hyposaline.

All of the Regional Parks at the lakes listed provide picnic, playground, and other day-use facilities. Boating occurs at all of the lakes and all but Cabri Regional Park provide camping and swimming opportunities. Several parks provide swimming lessons and other recreation programs. Most of the lakes are used to some degree for angling, although many require fish stocking. Several of the parks have golf courses, cottage developments, and a variety of other recreational facilities and services. Although they are primarily summer facilities, many parks are seeing increased winter use. Cross country skiing, snowmobiling, winter cottaging and, in some cases, ice fishing are the main winter activities.

TABLE 2: Regional Parks on Saline Lakes

REGIONAL PARKS	Salinity (g/L)	Beach/Swimming	Fishing	Boat Launch	Picnicking	Camping	Cottaging	Playground	Recreation Programs	Golfing
Antelope Regional Park Antelope Lake	7.68	x	x	x	x	x		x		x
Cabri Regional Park Cabri Lake	4.30		x	x	x			x	x	x
Clear Lake Regional Park Clear (Lonetree) Lake	9.68	x	x	x	x	x		x		
Manitou Lake Regional Park Little Manitou Lake	81.40	x		x	x	x		x		x
Redberry Lake Regional Park	19.42	x	x	x	x	x	x	x	x	x
Rockin Beach Regional Park Fife Lake	2.60	x	x	x	x	x		x	x	x
Saskin Beach Regional Park Fishing Lake	4.32	x	x	x	x	x	x	x	x	
St. Brieux Regional Park Lake Lenore	6.36	x	x	x	x	x		x	x	x
Sufferin Lake Regional Park Manitou Lake	25.15	x		x	x	x	x	x		x
Tramping Lake Regional Park	8.51	x		x	x	x	x	x		x
Wakaw Regional Park Wakaw Lake	3.48	x	x	x	x	x	x	x		x
Waldsea Regional Park Waldsea Lake	22.98	x		x	x	x	x	x	x	

The Regional Park program was established in 1960 to provide all residents of the province's populated area with outdoor recreation opportunities reasonably close to home. Regional Parks, which are funded by provincial (2/3) and municipal (1/3) grants, are locally controlled and operated. There are 101 Regional Parks in the entire system at the moment, of which 12 have a saline lake resource base. Taken together, these 12 parks represent a capital investment of nearly $4 million, not including land. In addition, countless hours of volunteer labour and donated materials and equipment have gone into their development. Well over 300,000 visitors made use of the 12 saline lakes parks during the 1984 season and, in general, annual

visitation is increasing steadily (C. Gabel, Saskatchewan Dep. of Parks and Renewable Resourses, pers. comm. 1985).

The significance of these saline lake-based parks for regional water-based recreation should not be underestimated, especially in a province in which certain areas suffer from a dearth of surface water suitable for public purposes. The research and development of this paper have led the Department of Parks and Renewable Resources to realize both the current benefits and the untapped potential for further saline lake recreation development. Given the right mix of physical characteristics, landscape, access and attraction, further development of recreational facilities on saline lakes is highly probable. Certainly, their use to date demonstrates a high degree of public acceptance, and augurs well for potential saline lake recreation in Saskatchewan.

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FISH IN SASKATCHEWAN ENDORHEIC SYSTEMS AND SALINE WATERS

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ABSTRACT

The saline lakes of Saskatchewan have no endemic species of fish, but have 16 species that otherwise occur in fresh water. The climatic changes since glaciation have made endorheic systems quite inhospitable to fish. The minnow family (Cyprinidae) contributes the largest number of species (8) to this fauna but the stickleback family (Gasterosteidae) is more tolerant of salinity and most widespread. The less saline lakes may be managed for fish production for both recreational and local use.

INTRODUCTION

Among the semi-arid regions of North America, Saskatchewan is distinguished by a large number of saline waters, some of which support fish. Ichthyological literature contains very little information on fish of inland mineral waters, perhaps because these waters contain few fish that have economic potential. Huntsman (1922) investigated the possibility of commercial fishing in the Quill Lakes, and Hankinson (1928) gave records of fish in Devil's Lake, North Dakota. Both authors recognized that the limiting condition was the tolerance of salinity and recorded the loss of fish populations as salinity increased. Rawson and Moore (1944) examined the distribution of fish in relation to salinity in a large series of freshwater and saline lakes. They provided a useful guide to the survival of several species under the stress of salinity. Rawson (1946) continued with experiments introducing whitefish and walleye in a saline lake, demonstrating that survival and growth were excellent but reproduction was not successful. Marshall and Johnson (1971) and Whitney (1967) record other species introduced into mineral waters. For Saskatchewan, the distribution records have been brought together by Atton and Merkowsky (1983) and that atlas is the main source of records used in this paper.

For purposes of this paper, saline lakes are defined as containing greater than 3,000 mg/L of total dissolved salts (TDS) following Hammer et al. (1983). Most of the lakes studied by Rawson and Moore (1944) are subsaline and not included here. Data on nine lakes that were saline in 1940 are used.

Endorheic regions are those in which streams enter closed lake basins where mean annual evaporation is approximately equal to inflow.

In general, endorheic systems have a freshwater component which is peripheral and a central saline component. The fish fauna of such internal drainages may thus choose their habitat from freshwater streams, often seasonally ephemeral, and central lakes which usually show wide changes in salinity over longer periods of time.

The locations of lakes discussed in this paper may be found in the Gazetteer of Canada, Saskatchewan (1969) or in Liaw and Atton (1981).

This study surveys the fish in Saskatchewan endorheic systems and comments on how salinity affects their distribution, abundance and management.

SASKATCHEWAN ENDORHEIC SYSTEMS

Endorheic systems developed since 12,000 B.P. following the recession of pleistocene ice and the draining of the great proglacial lakes. These systems lie in two large areas separated by the Missouri Coteau (Figure 1). The northeastern area lies on the Saskatchewan Plain while southwestern systems are on the higher Alberta Plain. Dissection of these areas by the Saskatchewan River, Eagle Creek, Swift Current Creek and Lanigan Creek has produced at least seven endorheic systems that are now associated with the Saskatchewan-Nelson drainage system. Isostatic rebound no doubt affected the developing drainages. The two southwestern systems were probably associated with the Missouri drainage during the early recession of the ice. One very small area, Pekakumew, is in the present-day Churchill River drainage.

Some saline lakes are not at the centre of an endorheic system. Wakaw Lake and Fishing Lake remain hyposaline because they are headwaters from which there is some outflow to the Carrot and Whitesand Rivers respectively. These lakes must have a mean annual discharge less than their evaporative water loss. Goose, Binns, and Birchbark lakes in the Saskatchewan delta also behave as headwater lakes. Goose Lake is tributary to the Carrot River. It is strongly saline because of salt springs which flow into it.

The aquatic environment in the endorheic and saline areas since 12,000 B.P. has no doubt influenced the present day fish fauna. The changing climate since the recession of the ice may be summarized as follows based on Ritchie (1983), Last and Teller (1983) and Pettipas and Buckner (1983).

Late Wisconsinan	12,000-8,500 B.P.	cool	wet	fresh
Hypsithermal	8,500-5,000	warm	dry	saline
	5,000-1,500	moderate	moist	subsaline
Pacific Climatic	1,500- 700	warm	dry	saline
Episode	700-present	moderate	moist	saline

Figure 1. The distribution of major endorheic (interior) drainage systems (shaded) in Alberta and Saskatchewan (from Hammer, this publication).

The general trend, warmer and increasingly arid, tended to produce more saline waters in poorly drained and endorheic areas.

For about 3,000 years in the Late Wisconsinan, fish had access to the original waters of present day endorheic areas through southward draining channels and the large proglacial lakes. These lakes were up to 200 m deep toward the northeast, shallow toward the southwest, and provided a variety of habitats. With a maximum summer temperature of 15° C (Ritchie 1983) they were probably oligotrophic. After the draining of these lakes, spring floods still enabled smaller species to move long distances in waterways which at other seasons were dry, as such species do today.

During the hypsithermal period, with a maximum summer temperature of 20° C, many lakes became very saline, e.g. Lake Manitoba (Last and Teller 1983). There was a similar period of salinity about 1,000 B.P.

Thus salinity has selected and eliminated fish from various water systems at least three times, including the present day environment. Table 1 shows recent changes in some Saskatchewan lakes between 1940 and 1979. There was a general increase in salinity and a trend toward more hypersaline and mesosaline waters. The mean increase in salinity is about 50%. During the same period some other lakes became about 50% less saline.

TABLE 1: Salinity changes in some Saskatchewan lakes. Total dissolved solids (TDS) in g/L

	1938-1940[1]	1968-1979[2]
Little Manitou	118.70	182.00[3] (69)
Big Quill	30.02	53.21 (71)
Deadmoose		27.08 (71)
Little Quill	21.39	6.18 (76)
Waldsea		25.37 (71)
Manito	20.27	24.73 (74)
Redberry	14.95	21.39 (79)
Bitter	13.98	20.40 (69)
Antelope	13.64	8.88 (71)
Basin	12.05	22.00 (73)
Humboldt	8.54	4.32 (71)
Charron	7.08	10.80 (68)
Lenore	5.49	5.21 (75)
Old Wives		4.57 (71)
Twelve Mile		4.44 (71)
Fishing	3.18	4.32 (71)
Wakaw	2.92	3.73 (71)
Increasing (9 lakes mean)	24.79±36.23	38.06±55.94
Decreasing (4 lakes mean)	12.27± 6.95	6.15± 1.97

[1] Rawson and Moore 1944; [2] Liaw and Atton 1981; [3] 95.9 g/L in 1971 due to dilution via Saskatoon Southeast System.

Stratification of fresher water over saline water, augmented by temperature differences, can occur in saline lakes, especially in spring and early summer. Some fish are tolerant of greater salinity at lower temperatures, e.g. brook stickleback (Nelson 1968). Fish occurrence records related to the general salinity of the lake may, for these reasons, not be as informative as one might wish them to be.

FISH FAUNA IN SASKATCHEWAN SALINE WATERS

There are no endemic species of fish found in the endorheic systems. There are 48 species in 14 families recorded in the three drainage basins contiguous to the endorheic systems (Table 2); only 16 species are established in the closed drainages which are our topic. These are shown in Table 3. Four species in the minnow family occur only in the freshwater component of the endorheic systems. These are the lake chub, brassy minnow, finescale dace and longnose dace. These

species appear not to be tolerant to the salinity of the associated lakes. The 12 species in saline lakes occur more frequently in the hyposaline waters, e.g. Fishing, Lenore and Wakaw Lakes. The three larger species are recorded only from the less saline lakes. The remaining 9 species are minnow-like, all maturing at a small size. This suggests that the size of stream accessible to migrating fish may have an influence on their movement and survival. The two sticklebacks are the most common species and the most tolerant of high salinity.

The tolerance of salinity is difficult to examine accurately in the natural environment because of seasonal changes in concentration, cumulative trends (Table 1) and temperature effects, as discussed in the previous section. Table 4 shows some reported maximum salinities at which various species reproduce successfully. These are records of breeding populations. Salinities at which populations are reported not to survive are based on collected records and on stocking experiments where fish have grown very well, but survived only a few years. These salinity concentrations may represent lethal chronic toxicity.

TABLE 2: Number of species of each family of fish found in Saskatchewan drainages contiguous to and in endorheic systems.

		Missouri	Qu'Appelle	Saskatchewan	Total	Endorheic
Sturgeons	Acipenseridae			1	1	
Goldeyes	Hiodontidae	1	2	2	2	
Pikes	Esocidae	1	1	1	1	1
Mudminnows	Umbridae			1	1	
Trout	Salmonidae		2	3	3	
Minnows	Cyprinidae	9	12	14	16	8
Suckers	Catostomidae	3	5	6	6	1
Catfish	Ictaluridae	2	4	1	4	
Cod	Gadidae	1	1	1	1	
Trout perch	Percopsidae		1	1	1	
Sticklebacks	Gasterosteidae	1	2	2	2	2
Sculpins	Cottidae		1	3	3	
Bass	Centrarchidae		1		1	
Perch	Percidae	3	6	6	6	4
		21	38	42	48	15

TABLE 3: Occurrence of fish species in Saskatchewan Endorheic systems. X - species recorded in saline and freshwater parts of the systems. V - species recorded in freshwater component of the systems only. (See Appendix for common names of fish)

	Maple Creek System	Old Wives	Reed	Twelve Mile	Lake of Rivers	Fishing	Little Quill	Lenore	Basin	Humboldt	Deadmoose	Wakaw	Redberry	Manito
E. lucius			X			X		X		X		X		
C. plumbeus		V	V											
H. hankinsoni	V	V	V											
N. hudsonius						X						X		
N. stramineus						X								
P. neogaeus	V	V	V										V	
P. promelas	V	X		X				X					X	
R. cataractae	V	V	V											
S. margarita								X					V	
C. commersoni	V	V	V	V	V	X		X				X		
C. inconstans	V	X		X		X		X		X		X	X	X
P. pungitius						X	X	X	X		X		X	X
E. exile	V					X		X				X		
E. nigrum												X		
P. flavescens			X		X	X				X		X		
S. vitreum			X			X		X		X		X		
Total Species In Saline Waters (X)		2	3	2	1	9	1	8	1	4	1	8	3	2

The difference between these two salinity values may be called the range of salinity tolerance for a species. Figure 2 suggests some slight correlation between lower and upper values. More important, this range may be the only pertinent information in evaluating any fisheries management proposal of the more saline waters. Fish stocking projects which fail to obtain and consider such salinity tolerance information can see their money literally pickled. Some stocking projects can only be regarded as experiments (Rawson and Moore 1944).

Marshall and Johnson (1971) give details on the introduction of five species into Saskatchewan saline lakes. Currently, one more species, rainbow trout, is being introduced into Redberry Lake (Table 5). There is no evidence of success with any species where the salinity was greater than 17 g/L. Below this concentration, whitefish have been the most successful, and walleyes have shown some success. Cisco, catfish and smelt did not survive for one year. The current rainbow trout stocking has not yet produced an answer.

TABLE 4: Maximum salinities at which fish reproduce and/or survive.

	Salinity (g/L) at which:	
	Natural reproduction successful	Population survival unsuccessful
Northern pike	3.7 Wakaw	6.0 Lenore[1]
	4.2 Reed	17.0 Quill[1]
Walleye	3.7 Wakaw	15.8 Redberry[4]
Yellow perch	4.3 Fishing	17.0 Quill[1]
	4.2 Reed	
Fathead minnow	8.6 Devils[2]	15.2 Devils[2]
		13.4 Redberry[1]
Brook stickleback	13.4 Redberry[1]	15.0 Devils[2]
		>21.4 Redberry
Ninespine stickleback	6.2 Little Quill	>30.0 Deadmoose[3]
		>20.0 Quill[1]
White sucker	5.2 Lenore	17.0 Quill[1]
	4.3 Fishing	11.9 Basin
Iowa darter	4.3 Fishing	
	3.7 Wakaw	

[1] Rawson and Moore 1944; [2] Hankinson 1928; [3] Hammer 1975; [4] Marshall and Johnson 1971.

TABLE 5: Introduced species in saline lakes. V - successful for a short period of time; X - unsuccessful.

Lake	Whitefish	Cisco	Rainbow Trout	Smelt	Catfish	Walleye
Antelope						X
Humboldt						V?
Lenore	V					V?
Basin	V					
Redberry	V		?			V
Manito				X		
Little Quill	V	X			X	V
Big Quill	X	X			X	

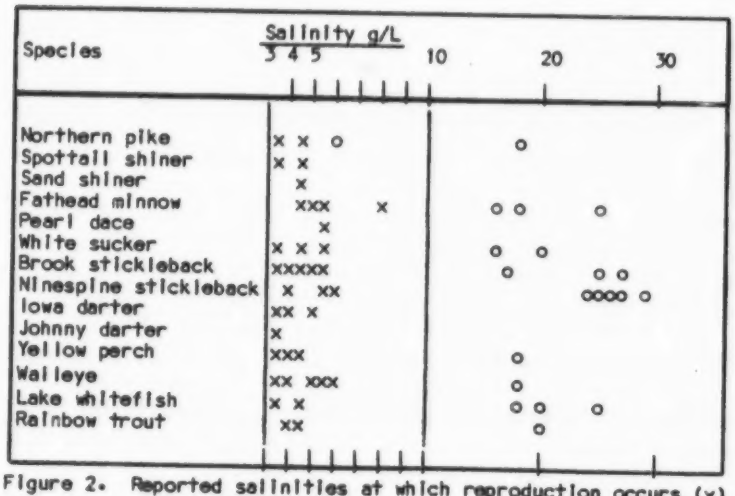

Figure 2. Reported salinities at which reproduction occurs (x) and populations do not survive (o).

DISCUSSION

All of the species in Saskatchewan endorheic systems were in the Mississippi and Missouri systems to the south and in glacial Lake Agassiz (Stewart and Lindsay 1983). During postglacial dispersal in late Wisconsinan times some species were much more widespread than at present, e.g. the brassy minnow. The fish of Saskatchewan endorheic and saline waters do not seem to alter the picture of postglacial dispersal, but are a vestige of a more abundant fauna.

Since the recession of the glaciers from the endorheic areas, lakes have become saline several times. Unlike the arid areas of the southwestern United States, no endemic salinity tolerant species has developed. This is probably because for about one-half of the 12,000 years the lakes were hyposaline at most, while for other shorter periods they were hypersaline or dessicated. Only two species are salinity tolerant; these are members of the marine family of sticklebacks (Gasterosteidae). The absence of any species of another marine family, the sculpins (Cottidae), emphasizes the severe habitat limitations of these endorheic drainages.

The opinion of Rawson and Moore (1944), that saline lakes of Saskatchewan have considerable possibilities for fish production, cannot be applied under the present day terminology defining saline lakes. Of the 14 saline lakes on their list, only 6 or fewer have any potential for fish production. Rawson's (1946) experiments with whitefish and walleye seem to have indicated the practical salinity boundaries for fish production as being about 17 g/L TDS. These experiments also showed that the whitefish can survive in large numbers and show high productivity in such monoculture conditions. These results may justify a similar experiment with rainbow trout, another salmonid, in Redberry Lake.

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APPENDIX. LIST OF FISH SPECIES.

Common Name	Scientific Name
Lake whitefish	*Coregonus clupeaformis*
Cisco	*Coregonus* sp.
Rainbow trout	*Salmo gairdneri*
Rainbow smelt	*Osmerus mordax*
Northern pike	*Esox lucius*
Lake chub	*Couesius plumbeus*
Brassy minnow	*Hybognathus hankinsoni*
Spottail shiner	*Notropis hudsonius*
Sand shiner	*Notropis stramineus*
Finescale dace	*Phoxinus neogaeus*
Fathead minnow	*Pimephales promelas*
Longnose dace	*Rhinichthys cataractae*
Pearl dace	*Semotilus margarita*
White sucker	*Catostomus commersoni*
Catfish	*Ictalurus* sp.
Brook stickleback	*Culaea inconstans*
Ninespine stickleback	*Pungitius pungitius*
Iowa darter	*Etheostoma exile*
Johnny darter	*Etheostoma nigrum*
Yellow perch	*Perca flavescens*
Walleye	*Stizostedion vitreum*

SALINE WATERS: AGRICULTURAL USES

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ABSTRACT

By definition, saline waters (TDS greater than 1,000 mg/L) are not preferred for irrigation. With careful management, higher leaching fractions, use of salt tolerant crops and sandier soils, irrigation with saline waters up to 3,000 mg/L can be achieved. It is estimated that 23% of Saskatchewan's saline lake areas could potentially be utilized for irrigation. Probably, less than 40% of the groundwater reserves in the more extensive bedrock aquifers could be used for irrigation. Most wastewaters would likely be acceptable given the availability of compatible soils.

If halophytic plants become a feasible source of fodder or forage, saline waters up to 10,000 mg/L could readily be used to increase productivity of these new crops. In such a situation, about 60% of Saskatchewan's saline lake area could be utilized for irrigation. Neither groundwaters nor wastewaters should present a salt problem to halophytes.

Livestock tolerance of saline waters is a function of livestock type and age. Cattle, sheep and, to a lesser extent, pigs can tolerate saltier waters (5,000 - 7,000 mg/L) than poultry (3,000 - 4,000 mg/L). Younger animals are more susceptible than older animals. Assuming a 5,000 - 7,000 mg/L upper limit of protection, then about 41% of the saline lake area is useable for livestock watering. Groundwaters are generally suitable but secondary trace element deficiencies can occur. Wastewaters are not generally recommended as a source of water for livestock because of the presence of pathogens.

INTRODUCTION

There are about 26 million ha (65 million acres) of farmland in Saskatchewan of which 19 million ha (48 million acres) (75%) are improved farmland (Cameron et al. 1982). Farmland occupies about 46% of the total land area in Saskatchewan. Most of this land area lies south of the 54th parallel.

It is estimated that about 12% of Saskatchewan is covered by water (Richards and Fung 1969). This figure includes the more permanent water bodies (lakes and rivers) and comprises a total area of about 8 million ha (19 million acres). Most of the water bodies in Saskatchewan are north of the 54th parallel.

Often in springtime, and sometimes throughout certain years, part of the agricultural land is inundated. These inundated lands, or sloughs, are both large and small and are usually not considered permanent even though during a wet cycle some may hold water all year. The flooded land area fluctuates with the weather from year to year.

It has been estimated that there are 6-8 million sloughs south of the 54th parallel (Korven and Heinrichs 1971). Although one might expect that most temporary (spring) sloughs are non-saline, there will be a portion which would be considered moderately to very severely saline. Fresh water may enter the saline sloughs each year but, with mixing and evaporation, the waters soon become saline.

AGRICULTURAL USES

There are two potential uses for saline waters in agricultural industry. One is as a water source for livestock including cattle, horses, sheep, pigs and poultry. The other is as a water supply for irrigation of agricultural crops. Domestic or home use of saline water will not be covered. Similarly, the use of saline waters on agricultural land for such activities as fish or shrimp farming, or for such futuristic ideas as algae production, will be left for others to discuss.

WATER SOURCES

There is not a rigid set of conditions that define saline water. The definition will most likely vary from discipline to discipline and will probably be a function of the primary use of the water. For the purposes of this paper, having an agricultural bias, the limit has arbitrarily been set at 1,000 mg/L total dissolved solids (TDS). This paper will concentrate on the potential use in agriculture of saline waters having a total dissolved solid (primarily inorganic salts) content greater than 1,000 mg/L.

From an agricultural viewpoint there are three main categories (sources) of saline waters. These are:

1. Surface water
2. Groundwater
3. Secondary (effluent) water
   (a) municipal
   (b) agricultural
   (c) industrial.

Surface waters from streams, rivers, lakes, spring runoff, reservoirs, dugouts and sloughs make up the largest agricultural source of water and this text will concentrate on the use of these waters.

The use of groundwater for agricultural irrigation is limited at present. Most of the use is for domestic or livestock water supplies, but there is some pressure to use this resource for irrigation.

Secondary or effluent waters play a minor role in agriculture in terms of water supply. There is, however, increasing pressure to utilize agricultural land for disposal of these wastewaters. From the agricultural and environmental viewpoint, there is concern about the salt content and other elements in effluents and their effect on soil properties.

SALINE LAKES IN SASKATCHEWAN

The agricultural use of saline waters is primarily a function of the total salt content. The type of salts in the water also plays a role. For these reasons an examination of saline lake chemistry was conducted as part of this study. This exercise also yielded a clearer perception of the extent of saline lake waters in Saskatchewan.

Rawson and Moore (1944), Rutherford (1970) and Hammer (1978) compiled excellent papers on the water quality of the major saline lakes in Saskatchewan. As well as measuring the TDS and major ions of water samples from the various lakes, these authors reported lake areas. The results they obtained have been grouped by region and lake (over time) and are presented in Appendix I. The chemical composition was used to calculate the sodium adsorption ratio (SAR) and the adjusted sodium adsorption ratio (Adj. SAR), two parameters used in determining the quality of water for irrigation purposes.

In order to summarize the information, three TDS categories -- 1,000 - 3,000 mg/L (moderately saline), 3,000 - 10,000 mg/L (highly saline) and greater than 10,000 mg/L (severely saline) -- were selected and the lakes for each of three regions in Saskatchewan were grouped in their respective TDS categories (Table 1).

The West-Central region included the lakes north and west of the South Saskatchewan River. The total saline lake area (statistical population) sampled was approximately 456 km^2 (113,000 acres) of which about 62% of the lake areas were severely saline and the remainder were evenly divided between moderately and highly saline. Manito and Redberry were the dominant lakes in the severely saline category comprising about 65%.

TABLE 1: Classification of Saskatchewan Saline lakes by regional location and TDS (mg/L). Lake surface area (km^2) is shown beside each lake.

TDS (mg/L)	1,000 - 3,000		3,000 - 10,000		10,000	
West & Central (W&N of S. Sask. R.)	Atton	2.0	Bad	12.2	Aroma	8.1
	Big Gully	3.0	Cabri	10.0	Bitter	6.5
	Jackfish	62.0	Little Manito	6.5	Blaine	13.0
	Kinderline	.6	Lucky	24.2	Landis	3.3
	Murray	16.0	Puntia	15.4	Manito	114.0
	Round	1.3	Rabbit	4.1	Pekakumew	9.0
	Wilson	2.6	Reflex	14.7	Redberry	70.0
					Stockwell	5.9
					Tramping	22.3
					Van Scoy	6.4
					Whiteshore	23.0
	Total Areas	87.5 km^2		87.1 km^2		281.5 km^2
East - Central (E. of S. Sask. R., N. of Qu'Appelle Valley)	Goodspirit	44.0	Birchbark	2.9	Arthur	2.5
	Margo	2.6	Boucher	6.7	Basin	62.0
	Ponass	48.0	Buffer	19.9	Big Quill	420.0
	Potato	12.0	Charron	6.5	Deadmoose	5.0
			Fishing	36.0	Goose	12.7
			Humboldt	4.4	Houghton	22.1
			Lenore	93.0	Little Manitou	14.0
			Little Quill	182.0	Louis	1.9
			Wakaw	13.0	Marie	1.6
					Middle	13.4
					Muskiki	17.0
					Olivier	2.0
					Patience	10.0
					Porter	1.9
					Sayer	2.0
					Waldsea	5.0
	Total Areas	106.6 km^2		364.4 km^2		593.1 km^2
Qu'Appelle and southern Saskatchewan	Carlyle	10.0	Big Muddy	38.9	Antelope	15.0
	Crane	26.5	Big Stick	10.7	Bitter	17.0
	Crooked	15.0	Chaplin(s)	27.0	Chaplin(E,W)	33.0
	Echo	10.0	Golden Prairie	.3	Lonetree	1.4
	Fife	30.2	Lake of Rivers	36.7	Midskogen	16.7
	Katepwa	13.0	Old Wives	296.0	West Coteau	9.1
	Kenosee	8.0	Reed	20.0	Willowbunch	38.2
	Last Mountain	210.0	Twelve Mile	2.6		
	Mission	10.0				
	Pasqua	15.0				
	Round	10.0				
	Total Areas	357.7 km^2		432.2 km^2		130.4 km^2
Total Areas All Regions		551.8		883.7		1005.0

* data from Rawson and Moore 1944; Rutherford 1970; Hammer 1978.

The East-Central region included the lake areas east of the South Saskatchewan River and north of the Qu'Appelle-Last Mountain Lake system. The estimated total saline lake area that was sampled was

1,064 km^2 (263,000 acres) of which about 56% was severely saline, 34% highly saline and 10% moderately saline. Big Quill Lake dominated the area of the severely saline lakes with 420 km^2 out of the 593 km^2, comprising about 71% of this category. Similarly, Little Quill Lake made up 50% of the highly saline lake category in East-Central Saskatchewan.

In Southern Saskatchewan, including the Qu'Appelle system, the total saline lake area sampled was approximately 920 km^2 (227,000 acres). Approximately 14% of the lake area was severely saline while 47% was higly saline and 39% moderately saline. Last Mountain Lake comprised about 59% of the moderately saline lake area, while Old Wives Lake comprised 68% of the highly saline lake area (based on the areas given in Table 1).

In summary, approximately 80% of the reported lake area in Saskatchewan, south of the 54th parallell, represents water containing greater than 1,000 mg/L of total dissolved salts. Of this 80%, an estimated 41% is severely saline, 36% highly saline and 23% moderately saline. In addition to the lakes listed in Table 1, there are numerous small water bodies not reported in the literature and for which salinities cannot be provided.

The salinity of southern Saskatchewan surface waters can be compared with those from North Dakota. Maianu (1984) reported the electrical conductivity of water samples from 78 lakes routinely monitored between 1948 and 1982. More than 50% of the samples had less than 1,000 mg/L TDS (estimated from conductivity). British Columbia lakes are even less saline, rarely exceeding 350 mg/L TDS (Wilcox and Mason 1963).

GROUNDWATERS

Mollard (1964) estimated that approximately 9×10^{11} m^3 of water are stored in the glacial drift beneath southern Saskatchewan. He indicated that the groundwater reservoir in southern Saskatchewan is essentially full but that the groundwater tends to be highly mineralized relative to surface waters. Rutherford (1967) conducted a water quality survey of Saskatchewan groundwaters and developed the classification shown in Table 2.

Rutherford's results showed that the groundwaters of the upper glacial drift were of better quality than those of deeper formations. Unfortunately, most of the well-defined aquifers, suitable for pumping large volumes of water, are located within the deeper strata where water quality is marginal. The aquifers in the upper glacial till are, generally, neither as extensive nor as well defined as those in the underlying formations.

TABLE 2: Classification of some Saskatchewan groundwaters according to dominant mineral composition (Rutherford 1967).

Water Type	TDS (mg/L)	No. of samples	Geological Occurrence
$Ca(Mg)(HCO_3)_2$	406-850	813	Mainly in upper glacial drift, some in Cypress Formation as well as Ravenscrag and Belly River in presence of coal seams
$CA(Mg)SO_4$	1786-2516	1173	Mainly lower glacial drift, some upper drift, Cypress Formation and sporatic in Bearpaw and Belly
Na_2SO_4	2054-3950	514	Mainly lower glacial drift Eastend, Bearpaw, Ravenscrag, Belly River, and Lea Park Formations
$NaCl(SO_4)$	2572-4910	13	Belly River, Bearpaw and Marine Shale Formations
$NaHCO_3$	748-1552	244	Belly River, Cypress, Ravenscrag, Eastend, Bearpaw, and Lea Park Formations
$NaCl(HCO_3)$	1350-4637	83	Belly River, Bearpaw, Ravenscrag, and Marine Shale Formation

Recently, Bachman, Cameron, Jame and Nicholaichuk (1982) studied the feasibility of using Saskatchewan groundwaters for irrigation. They concluded that a large portion of the groundwater in Saskatchewan is of marginal quality and that prolonged irrigation could cause problems on many soil types. Gillies et al. (1985) summarized the results of two experimental groundwater irrigation projects in Saskatchewan, one near Donavan (50 miles SW of Saskatoon), pumping from the Tyner Valley Aquifer and one near Watrous (80 miles SE of Saskatoon) pumping from the Hatfield Valley Aquifer. Both the Donavon and Watrous systems are irrigating deep, coarse-textured soils with 2200 mg/L and 2870 mg/L TDS groundwaters having SARs of 13.5 and 15.4, respectively. Gillies et al. observed a salt and SAR build-up in the soil. There was no visible effect of this accumulation on crop production.

Groundwater is used world-wide both as a sole source and as a supplemental source for irrigation. Hallsworth (1981) reported the use of groundwaters with salinities of 2,000 mg/L TDS to irrigate eucalpytus trees and date palms and, of greater interest, groundwaters with salinities up to 16,000 mg/L to irrigate casuarina and tamarisk trees on the sands of Arabia.

EFFLUENT WATERS: MUNICIPAL AND INDUSTRIAL

Disposal of wastewaters or effluent waters on agricultural land is becoming both economically and environmentally acceptable in many areas (Environment Canada 1984). In Saskatchewan, the town of Swift Current and the city of Moose Jaw have set up large irrigation projects to dispose of secondary lagoon effluent. Other communities have followed this lead (Nicholaichuk *et al.* 1982; Underwood McLellan Ltd. 1978; Wiebe 1982).

The salt content of lagoon water is generally correlated with the salt content of the water supply. Industrial wastewaters tend, however, to reflect industry processes. Some of the available literature was surveyed and typical values for salt content in industrial and municipal wastewaters around the world are summarized in Table 3.

TABLE 3: TDS content of some municipal and industrial waste waters.

Location	TDS (mg/L)[11]	Source	Reference
Australia	700	Victoria	1
India	2,100	tolerance limits	1
Mexico	1,209	after mixing in discharge canal	1
Hungary	up to 3,500	canning wastes	1
	1,000-3,000	sugar refinery	
	1,112-1,602	two towns	
Belgium	1,310-1,905	canning wastes	1
Canada	420-2,450	lagoon effluent	2
California	467-1295	aerated lagoons	3
California	1,402	primary effluent	4
(various plants)	1,166	trickling filters	
	917	activated sludge	
	1,330	lagoons (ponds)	
Saskatchewan			
Swift Current	1,400-2,000	secondary lagoon	5
Moose Jaw	1,200-1,600	secondary lagoon	6
Biggar	1,024-2,240	secondary lagoon	7
Alberta			
Red Deer	560	secondary lagoon	8
Medicine Hat	840	secondary lagoon	8
Hanna	1,840	secondary lagoon	8
Brooks	1,190	secondary lagoon	8
Taber	630-1,260	secondary lagoon	9
S.E. Alberta	1,050	potato dehydrating	10
Central Alberta	4,900	cheese whey	10
S.E. Alberta	1,260	meat packing	10
S.W. Alberta	1,150	sour gas plant	10
S. Alberta	2,590	N fert. plant	10

[1] Sullivan *et al.* 1973; [2] Environment Canada 1984; [3] California State Water Resources Control Board 1984; [4] Pound and Crites 1975; [5] Jame *et al.* 1984; [6] Underwood McLellan 1978; [7] Wiebe 1982; [8] Regier and Wisherke 1984; [9] Graveland 1982a; [10] Graveland 1982b; [11] Electrical conductivity data were converted to TDS using the factor 1 mmho/cm = 700 mg/L

In terms of total irrigation, the volume of water used and the acreage irrigated by lagoon systems is relatively small. In Saskatchewan, the major concern with these waters has been their salt content and the compatibility of certain soil types to handle the salt composition and salt load.

WATER QUALITY FOR LIVESTOCK

Published water quality objectives, to ensure the safety of livestock, vary with the type of livestock and often with the region. Most provinces adjust their objectives to fit local conditions.

In addition to water quality tolerance differences between types of livestock, other factors can play an important role in determining specific water quality objectives (Alberta Committee on Water Quality 1972; Hart 1974; NAS/NAE 1973; NAS Subcommittee on Nutrient and Toxic Elements in Water 1974). Climate and temperature determine water consumption or intake requirements (Table 4). Species, age and condition of the animals are important. Younger and weaker animals are more susceptible to poor health or death when water quality deteriorates. The type of pasture (dry or green) and feed intake, coupled with habituation (what the animal is accustomed to), play an important role. Variation in water quality can have an adverse effect on cattle and sheep, particularly in the summer when water supplies evaporate and quantities of very saline water are ingested.

TABLE 4: Volumes of drinking water required by some domestic livestock.

	Volume of Water (L/day)		
Class of Livestock	Canada[1]	Saskatchewan[2]	Australia[3]
Dairy Cows	56-68	55	46-91
Milking Dairy Cows	---	160	---
Steers (400-1000 lbs)	>45	25-45	32-68
Dry Sows	---	10-20	---
Lactating Sows	13-22	20	9-23
Feeder Pigs (100-200 lbs)	---	7-10	---
Sheep	4-7	2-7	3-18
Laying Hens (100)	---	25-30	18-46
Broiler Chickens (100)	---	15-20	---
Horses	---	---	36-91

1 Department of Environment 1972
2 Saskatchewan Agricultural Services Co-ordinating Committee 1984
3 Hart 1974

Livestock are capable of consuming a large variety of microorganisms found in surface water, but stagnant pools should be avoided because of the danger of infection with internal parasites and toxic algae. Blue-gree algae, particularly, are a problem.

Total soluble salt concentration is used throughout the world as a convenient guide to the suitability of particular water livestock consumption. Several different guidelines have been published and some of these are summarized in Table 5.

TABLE 5: Summary of various objectives for total dissolved salt content of livestock drinking water supplies.

Australia (Hart 1974)			
	Desirable maximum concentration for healthy growth (mg/L)	Maximum[1] concentration at which good condition can be expected (mg/L)	Maximum concentration which may be safe for limited periods (mg/L)
Cattle (beef)	4,000	5,000	10,000
Cattle (dairy)	3,000	4,000	6,000
Horses	4,000	6,000	7,000
Pigs	2,000	3,000	4,000
Poultry	2,000	3,000	4,000
Sheep (dry feed)	4,000	13,000	(2)

[1] These limits apply when salinity is mainly due to sodium chloride (NaCl). If purgative salts such as magnesium sulphate and sodium sulphate are present in appreciable quantities, concentrations given should be modified.
2 Level depends upon the type of feed.

University of Saskatchewan (1965)					
	Rating of water supplies according to TDS (mg/L)				
	Good	Fair	Poor	Very Poor	Limit
Cattle	0-1,000	1,000-2,000	2,000-4,000	4,000-6,000	10,000
Horses (working)	0-1,000	1,000-2,000	2,000-3,000	3,000-5,000	6,000
Horses (others)	0-1,000	1,000-2,000	2,000-4,000	4,000-6,000	10,000
Poultry (chicks)	0-1,000	1,000-2,000	2,000-3,000	3,000-5,000	6,000
Poultry (full-grown)	0-1,000	1,000-3,000	3,000-6,000	6,000-10,000	15,000
Sheep	0-1,000	1,000-3,000	3,000-6,000	6,000-10,000	15,000
Humans	0-500	500-1,600	1,600-2,500	2,500-4,000	5,000

Alberta Committee on Water Quality for Livestock (1972)		
Species	TDS (mg/L)	Comments
Cattle & Sheep	7,000	NaCl salt less harmful than Na_2SO_4
Pigs	3,000	Acceptable with any combination of salts
	7,000	Acceptable for growing and finishing pigs; young pigs must adapt to salt
Poultry	0-1,500	No problems
	1,500-3,000	Satisfactory except for young turkey poults (<3 weeks)
	3,000-4,000	Satisfactory except for poults, chicks and ducklings
	4,000-7,000	Increased water consumption and watery droppings
	Greater than 7,000	Unsatisfactory

Saskatchewan Agricultural Services Coordinating Committee (1984)		
	TDS (mg/L)	Comments for Livestock and Poultry
	Less than 3,000	Satisfactory
	3,000-5,000	Satisfactory for livestock, can cause poor performance and death of poultry near upper limits
	5,000-7,000	Should not be used for pregnant, lactating, or very young animals
	Greater than 7,000	Avoid use for livestock if possible

National Academy of Sciences Subcommittee on Nutrient and Toxic Elements in Water (1974)	
Total Soluble Salts (mg/L)	Comments for Livestock
Less than 1,000	These waters have a relatively low level of salinity and should present no serious burden to any class of livestock.
1,000-2,999	These waters should be satisfactory for all classes of livestock. They may cause temporary and mild diarrhea in livestock not accustomed to them, but should not affect their health or performance.
3,000-4,999	These waters should be satisfactory for livestock, although they might cause temporary diarrhea or be refused at first by animals not accustomed to them.
5,000-10,000	These waters are probably unfit for swine. Considerable risk may exist in using them for pregnant or lactating cows, horses, sheep, the young of these species, or for any animals subjected to heavy heat stress or water loss. In general, their use should be avoided, although older ruminants, horses, and even swine may subsist on them for long periods of time under conditions of low stress.
Greater than 10,000	The risk with these highly saline waters is so great that they cannot be recommended for use under any conditions.

As can be seen from Table 5, guidelines vary somewhat from location to location depending upon specific animal species and protection levels afforded. In Saskatchewan, most of the intensive poultry, swine, feedlot and dairy operations are confined operations where feed and water supplies are delivered to one location. These intensive animal industries are not developed unless an assured supply of good quality water is on hand or can readily be obtained.

In Saskatchewan most water quality problems arise when cattle are on range or pasture where water supplies may be limited. It has been the general experience of veterinarians that, when the salt content in water exceeds 10,000 mg/L (TDS), animals will die from salt toxicity (D.W. McIntosh, D.V.M., Veterinary Pathologist, Saskatchewan Agriculture, pers. comm.). During a drought year many dugouts and ponds can reach these levels. The 1984 drought in southern Saskatchewan resulted in increased livestock deaths.

In managing livestock, two situations seem critical. Cattle deaths often occur when animals are moved from low salinity to high salinity water supplies. They must be allowed time to adjust to the higher salt content. Mortality can also occur when heat or travel-stressed cattle are exposed to high-salinity water. During such stress periods a good quality water supply is essential.

As a general recommendation for Saskatchewan range livestock, water quality should not exceed 5,000 - 7,000 mg/L TDS, especially if cattle are introduced to salty water without preconditioning.

In addition to total dissolved solids, livestock water quality objectives also include criteria on concentrations of the major ions, potentially toxic or harmful elements and heavy metals, microbes, pesticides and radioactive compounds. A comparison of some international and provincial standards is presented in Table 6.

TABLE 6: International and provincial water quality objectives for livestock watering supplies. Concentrations mg/L except where noted.

	Canada[1] (1979)	U.S. NAS/NAE[2] (1973)	Australia[3] (1974)	Saskatchewan[4] (1975)	Manitoba[5] (1979)	Alberta[6] (1972)	Montana[7] (1976)
Total Dissolved Solids (TDS)	2,500	3,000	3,000 poultry 5,000 cattle 13,000 sheep	4,000	3,000	7,000 cattle 5,000 swine 4,000 ducks 3,000 poultry 1,500 poults	2,860
pH	---	---	---	5.5-10.5	5.5-9.0	---	---
Sulphate (SO_4)	1,000	---	1,000	1,200	500	---	500
Chloride (Cl^-)	---	---	---	1,000	---	---	1,500
Sodium (Na)	---	---	---	1,000	---	---	2,000
Calcium (Ca)	1,000	---	1,000	---	---	---	1,000
Magnesium (Mg)	---	---	250-500	---	---	---	500
Alkalinity (as $CaCO_3$)	---	---	---	1,000-1,500	---	---	170
Nitrate + Nitrite (N)	20	100	90-200	68	100	100	100
Nitrite (NO_2-N)	10	10	10	---	10	---	10
Arsenic (As)	0.5	0.2	1.0	---	0.5	---	0.2
Cadmium (Cd)	0.01	0.05	0.01	---	0.05	---	0.05
Fluoride (F)	2.0	2.0	2.0	---	2.0	---	1.0
Lead (Pb)	0.05	0.1	0.5	---	0.1	---	0.1
Mercury (Hg)	0.003	0.01	0.002	---	0.01	---	0.01
Selenium (Se)	0.01	0.05	0.02	---	0.05	---	0.05
Copper (Cu)	0.5	0.5	0.5-2.0	---	0.5	---	0.5
Molybdenum (Mo)	0.01	---	0.01	---	---	---	---
Aluminum (Al)	5.0	5.0	---	---	5.0	---	5.0
Boron (B)	5.0	5.0	---	---	5.0	---	5.0
Chromium (Cr)	0.05	1.0	1.0-5.0	---	1.0	---	1.0
Zinc (Zn)	25	25	20	---	25	---	25
Vanadium (V)	0.1	0.1	---	---	0.1	---	0.1
Iron (Fe)	---	---	10	---	---	---	---
Toxic Algae	---	avoid blue-green	avoid blue-green	---	avoid blue-green	avoid blue-green	---
Total Coliform Bacteria (/100 ml)	---	avoid contaminated areas	1,000 (monthly mean) 5,000 (one sample)	---	---	---	---
Parasites	---	avoid	---	---	---	---	---

Organochlorine Pesticides							
Aldrin	0.001	0.001	0.001	---	0.003	---	Standards
Chlordane	0.003	0.003	0.003	---	0.040	---	based on
DDT & Metabolites	0.05	0.05	0.05	---	0.002	---	body meat
Dieldrin	0.001	0.001	0.001	---	0.003	---	accumulation
Endrin	0.005	0.0005	0.0005	---	0.002	---	(mg/kg)
Heptachlor	0.0001	0.0001	0.0001	---	0.005	---	
Lindane	0.005	0.005	0.005	---	0.02	---	
Methoxychlor	1.0	1.0	1.0	---	0.005	---	
Toxaphene	0.005	0.005	0.005	---	0.01	---	
Organophosphates & Carbamates (total)	0.1	0.1	0.1	---	specific values by type	---	
Herbicides							
2,4-D	0.03	0.02	0.02	---	4.0	---	
2,4,5-T	0.002	0.002	0.02	---	---	---	
2,4,5-TP	---	0.030	---	---	---	---	
Others (usually)	0.1	---	---	---	---	---	
Radiological							
gross alpha activity (pCi/L)	0.5	0.5	3.0	---	---	---	---
gross beta activity (pCi/L)	5.0	5.0	30.0	---	---	---	---

[1] McNeely et al. 1979 with 1979 Addendum; [2] National Academy of Sciences, National Academy of Engineering 1973; [3] Hart 1974; [4] Water Pollution Control Branch 1977; [5] Clean Environment Commission 1979; [6] Alberta Committee on Water Quality for Livestock 1972; [7] Botz and Pederson 1976

SALINE WATERS AND LIVESTOCK USE

In order to determine the utility of Saskatchewan's saline waters for livestock use, assume that grazing cattle and sheep have the greatest access to saline waters and that lakes or other saline waters having TDS concentrations less than 7,000 mg/L are acceptable after preconditioning. Using the information given in Tables 1 to 6, the potential livestock use of saline waters in Saskatchewan can be summarized as shown in Table 7.

TABLE 7: Summary of Saskatchewan water resources, south of the 54th parallel, suitable for livestock watering.

Saline Lakes	Percent Potentially Useable by Grazing Cattle & Sheep
West-Central	29%
East-Central	28%
Qu'Appelle-South	62%
All Saskatchewan	41%

Groundwaters: Most of Saskatchewan's glacial drift and bedrock aquifers contain water of a quality suitable for livestock use. Elements such as sulphates, iron, and molybdenum in excess can indirectly induce copper deficiencies in livestock (Smart 1983; Smart and Gudmundson 1980). Deficiencies in other trace elements, including zinc, iodine, manganese, and selenium, must also be guarded against.

Wastewaters: Wastewaters are not recommended for livestock consumption because of the potential for direct ingestion of toxic pathogens or toxic elements.

In summary, about 40% of the saline lake waters in Saskatchewan are suitable for use by range cattle and sheep. Groundwaters are generally acceptable for most livestock but may require nutritional adjustments for trace element deficiency. Wastewaters should not be consumed by livestock.

WATER QUALITY OBJECTIVES FOR IRRIGATION

One of the major problems that has plagued committees in assessing and setting water quality criteria for irrigation is the variety and variability of factors and interactions that play a role in irrigation. In addition to the dissolved salt content (salinity) of irrigation waters, factors such as chemical composition of the water, interaction of the water with the soil, salt tolerance of the crop being irrigated, leaching fraction, climate of the area and management play important roles. The presence of specific ions, toxic compounds or elements, micro-organisms and pesticides must also be considered.

Recently, the matter has been further complicated by the "new" or "exotic" sources of water. There is increasing pressure to use agricultural land for disposal of secondary lagoon effluent waters. Small and fairly isolated irrigation tracts utilizing groundwater are being

tested. The disposal of some industrial waters by irrigation is being considered. These sources of water are relatively new to agricultural irrigation in western Canada and have caused some changes in thinking with regard to irrigation standards. At present both the Federal Government of Canada, the Saskatchewan Government and other provincial governments have undertaken major programmes to examine and set more appropriate criteria.

The intent of this portion of the paper is to assess the possible use of saline waters for irrigation. Water quality criteria relating to salinity, in particular total dissolved solids (TDS) and sodium adsorption ratio (SAR) are highlighted. The various specific ion tolerances including B, Cl, Na and SO_4 will not be discussed in detail.

Ayres and Westcot (1976) compiled a useful document on water quality for agriculture. Their recommended guidelines have been widely used. In 1984, they updated their guidelines and these are summarized in Table 8.

TABLE 8: Water quality guidelines for irrigation combining electrical conductivity (EC) and sodium adsorption ratio (SAR). (California State Water Resources Control Board 1984) The table indicates potential problems with varying water quality.

SAR	EC (mmhos/cm)		
	No Problems	Increasing Problems	Severe Problems
0-3	Greater than 0.7	0.7-0.2	Less than 0.2
3-6	Greater than 1.2	1.2-0.3	Less than 0.3
6-12	Greater than 1.9	1.9-0.5	Less than 0.5
12-20	Greater than 2.9	2.9-1.3	Less than 1.3
20-40	Greater than 5.0	5.0-2.9	Less than 2.9
	1mmho = 700 mg/L TDS		
	Specific ions (mg/L) that will cause		
	No Problems	Increasing Problems	Severe Problems
Chloride woody plants	Less than 140	140-350	Greater than 350
Annual crops		Use salinity tables	
Boron most crops	Less than 0.7	0.7-2.0	Greater than 2.0

A number of authors have addressed the problems of water quality for irrigation (Eaton 1942; Wilcox 1948; Doneen 1949; Bernstein 1964; Wilcox and Durum 1965; Rhoades 1971; Christiansen and Olsen 1977). Prior to Ayres and Westcot, however, the U.S. Salinity Laboratory Staff (1954) manual on diagnosis and improvement of saline and alkali soils was the preferred reference and continues to be important.

It was thought that one of the advantages of the water quality criteria proposed by Ayres and Westcot (1976) was a method of accounting for the effects of carbonates and bicarbonates in irrigation water on the precipitation of calcium and magnesium. Large amounts of bicarbonate ions in irrigation water will, upon drying in the soil, precipitate calcium and remove it from the soil solution; this leaves sodium in place of calcium and increases the sodium hazard (Eaton 1950; Bower et al. 1967; Rhoades 1968). Continued precipitation of calcium and magnesium through the use of high bicarbonate irrigation water can alter a calcium dominant soil so that it becomes sodium dominant.

Sodium can adversely affect the physical condition of soil so that when the soil is wet it disperses clay particles or "runs together" and becomes very tight. Water will not easily move through a soil when it is in this condition.

The adverse effect of sodium on the soil is more related to the ratio of sodium to total cations in the water than to the absolute amount of sodium present. The adjusted sodium adsorption ratio (Adj SAR) includes the relative activity of the sodium ions as they react with the clay (SAR) and the added effects of the precipitation and dissolution of calcium in soils as related to CO_3 and HCO_3 concentration, viz:

$$\text{Adj. SAR} = \text{SAR}\,[1 + (8.4 - \text{pHc})]$$

$$\text{where SAR} = 1.41 \times \frac{\text{Na}}{(\text{Ca} + \text{Mg})^{\frac{1}{2}}} \text{ as meq/L}$$

pHc from Standard tables (related to Ca + Mg and $CO_3^{-2} + HCO_3^{-1}$)

The calculated SAR and Adjusted SAR values for some Saskatchewan saline lakes are presented in Appendix I. In almost all cases the calculated Adjusted SARs were 2 to 3X the standard SARs. Some researchers think that the adjusted SAR values are too high and over-estimate the real sodium effect (Environment Canada, 1984).

"REVISING" OBJECTIVES FOR IRRIGATION

There is an increasing demand for the use of lower quality waters for irrigation as good quality waters become limited, particularly in

arid regions where irrigation with poor quality water can at least ensure a crop. Similarly, there is an increasing demand from urban centres to use agricultural land for disposal of treated sewage and industrial wastes.

As a result of this increased demand, researchers have been and continue to be in the throes of re-examining and re-evaluating water quality objectives. It is expected that, in the next decade, major advances in our understanding and rationale for objectives will be forthcoming. A brief review of current changes and rationales is appropriate here.

Salinity

For standard irrigation with wastewaters, Environment Canada (1984) suggests that waters with 1.3 mmhos/cm conductivity (900 mg/L TDS) should present no problem, but waters with greater than 3.0 mmhos/cm (2,000 mg/L) can cause severe problems. For high leaching rate irrigation, however, the limit for no problems has been raised to <4.0 mmhos/cm (2,800 mg/L). The rationale is that the higher leaching fraction will reduce salt accumulation in the rooting zone.

Another common approach in the utilization of poorer quality waters is to grow plants which are more salt tolerant. Thus, in sewage effluent irrigation projects, alfalfa and other more salt tolerant forages are often used, replacing the less tolerant cereal varieties. There is some documentation on the salt tolerance of various plant species, although little has been developed specifically under Canadian and Northern USA Prairie conditions (Kearney and Scofield 1936; Bernstein 1974; Ingvalson et al. 1976; Maas and Hoffman 1977; McKenzie et al. 1983; François 1981; Maas 1985).

Pesearchers have long recognized that soil texture plays an important role, with sandier soils capable of handling larger salt loads with less adverse effects than heavier soils. Internal drainage, depth to water table and depth to less permeable materials, can become critical, particularly in shallow soil profiles. In fact, where poor quality irrigation waters are available, soil suitability becomes increasingly important. Irrigation sites with compatible soils to suit the water quality must be carefully selected.

Permeability

For a given soil texture, potential alteration of the permeability of the soil becomes primarily a function of the SAR and TDS of the irrigation water (thus soil water) and the clay type within the soil.

The authors of the Environment Canada (1984) manual on wastewater disposal felt that the adjusted SAR calculations were too high on most wastewaters and favoured the use of ordinary SARs for their standards. Suarez (1981) introduced a new method (Adj. RNa) for estimating the SAR of soil or drainage water. His approach has been considered more acceptable than the Adjusted SAR calculation (California State Water Resources Control Board 1984). A comparison of the three calculations is presented in Table 9 for some selected lake data from Appendix 1. In these calculations, there does not appear to be a large difference between the values of SAR and Adj. RNa.

TABLE 9: Comparison of SAR, Adj. SAR and Adj. RNa values for some Saskatchewan lakes.

Lake	TDS (mg/L)	SAR	Adj. SAR	Adj. RNa
Jackfish	1,932	4	12	4.1
Last Mountain	2,120	7	19	7.4
Old Wives	4,600	15	47	16.2
Little Quill	5,832	8	28	8.8
Manito	23,900	84	342	85.3
Big Quill	50,880	28	166	28.8

High salinity or TDS can override any potential effect of excess sodium (high SAR). In fact, at a given SAR, the infiltration rate increases as salinity increases. The high salt concentration (electolytic concentration) counteracts any sodium displacement. The irrigation waters which present the greatest problems with regard to physical impairment of the soil are waters which are relatively high in sodium and low in total salt content (Rhoades 1977; Oster and Schroer 1979; Rhoades 1982).

The line in Figure 1 represents a generalized boundary between stable and unstable soil physical conditions for the irrigation water or the soil solution. Combinations of salinity and SAR (or adjusted RNa) values that lie above the line are not expected to cause dispersion or clay swelling. Those values that lie below the line can create permeability problems.

If the SAR in the topsoil is greater than 10, large reductions in permeability can occur if rainfall reduces soil salinity to levels less than 1 dS/m. Reductions of soil permeability below the surface are usually not a problem as the increased level of salinity due to the crop water uptake should offset any bad effects of exchangeable sodium.

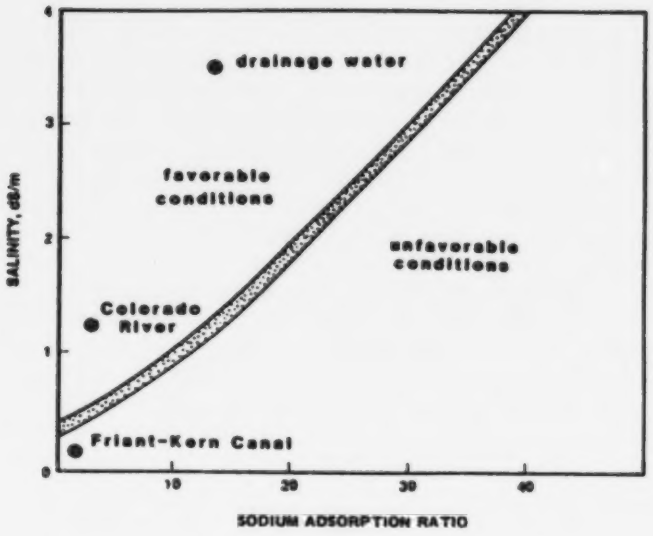

Figure 1. Salinity and sodium adsorption ratio boundary that divides combinations of both measures into two categories; those which promote good permeability and those which do not. The graph can be used for both irrigation water and soil saturation extract compositions (After California State Water Resources Control Board 1984).

Texture, in particular clay content and the mineralogy or type of clays, can be a determinant in the sodium permeability problem. The montmorillonite (2:1 crystal lattice) expanding clays present the largest problem with regard to colloidal particle dispersion and reduced permeability (Ayers and Westcot 1976). The lesser expanding illite-vermiculite (2:1 crystal lattice) are not as bad but still present problems. The least affected clays are the kaolinites and sesquioxides (1:1 crystal lattice). It also follows that soils with low clay contents are less affected.

Other Problems

In addition to salinity and permeability, irrigation waters may contain other compounds which may be toxic to the crops being grown. The following parameters are usually examined fairly closely prior to granting approval to irrigation projects.

1. Specific ion toxicity, eg. B, Cl, Na
   - depends upon crop sensitivity
2. Trace elements -- heavy metals are sometimes a concern in wastewaters
3. Biological pathogens
4. Toxic organics
5. pH and corrosion
6. Plugging potential (drip systems)
7. Others

SALINE WATERS AND IRRIGATION

The objective of this review is to determine the use of saline waters in agriculture. To this end, the lake data summarized in Table 10 as well as the various data summarizations of groundwater and wastewater quality in other tables will be compared to irrigation water quality objectives. To simplify matters, it is assumed that sufficient land mass is available near the water sources so that waters with concentrations of salt up to 3,000 mg/L can be utilized. In other words, the soil textures and drainage positions of the land area that can be irrigated are such that sufficient sandy soils are available for the 3,000 mg/L waters and degrees of heavier soils available for the better quality waters. Further, we will assume that saline waters exceeding 3,000 mg/L are generally not acceptable for irrigation.

TABLE 10: Irrigation potential of Saskatchewan surface, ground and waste waters.

Saline Lakes of Saskatchewan	Potential Irrigation Use
West-Central	- 19% of lake areas
East-Central	- 10%
Qu'Appelle-South	- 39%
All Saskatchewan	- 23%
Groundwaters	
Upper and Lower Glacial Drift	water quality generally acceptable but quantity may be limited
Large Interglacial-Bedrock aquifers	estimated that less than 40% of these waters would be considered acceptable
Tyner Valley and Hatfield aquifers	quality varies with location, but generally unacceptable except for coarse textured soils
Wastewaters	
Lagoons where town water supply is from surface waters	Usually acceptable for irrigation, unless surface water supply is salty
Lagoons where town water supply is from groundwater	Varies with aquifer, but some waters from deeper aquifers are too salty and unacceptable
Industrial	Unknown, acceptability judged on individual basis
Agricultural	Unknown, probably similar to lagoon but may utilize some primary effluent

Most saline lakes in Central Saskatchewan are too saline for irrigation purposes, although about 39% of the lake systems in the Qu'Appelle (including Last Mountain) and Southern Saskatchewan may be useable. It is estimated that greater than 60% of the bedrock aquifers would be considered unacceptable for irrigation. Irrigation with wastewaters will continue to be judged on a site-specific or individual merit basis.

HALOPHYTES AND IRRIGATION

Saskatchewan has around 2 million acres of salt-affected soils where most cereal production is limited. Several authors have suggested that saline areas, or areas having supplies of salty or brackish water, could lend themselves to the production of halophytic plants -- plants which survive in salty environments (Felger and Mota-Urbina 1982; Glenn and O'Leary 1984; Govdin 1979; O'Leary 1979; O'Leary and Glenn 1984; Pasternak 1982; Somers 1975, 1979; Ungar 1974).

Epstein et al. (1979) has worked on genetic selection of barley, wheat and tomato varieties which can survive (germinate to set seed) in 70-90% seawater solution. Seawater has a salt concentration of around 25,000 mg/L. Of the 6,200 barley genotypes screened by Epstein only 22 or 0.13% survived. Only 5,000 wheat entries were screened and 40, or 0.8% were promising, 12 particularly so. A cross between a wild tidewater tomato and a domesticated tomato produced a salt tolerant genotype capable of producing cherry-sized tomatoes at 70% seawater concentration. Continued research in these areas should prove beneficial and could provide new lines of our common cereal and vegetable plants. These new genotypes would adapt well to a saline environment and could be irrigated with salty waters.

Some of the common halophytes have been studied directly and indirectly by various ecologists (Braidek et al. 1984; Dodd and Coupland 1966; Fraser and Russell 1954; Looman and Best 1979; Millar 1976). Mudie (1974) and others (op. cit.) have outlined various uses of halophytes. A list of potential uses of halophytes is outlined in Table 11.

In Saskatchewan, halophyte production would most likely lean towards the fodders and forages, primarily for livestock. Protein and oil production and possibly alcohol production (for fuel) might be of interest to some. Of course the development of a halophytic agriculture would require that obstacles such as cold hardiness, seed germination, harvesting, post-harvest regeneration, palatability, limiting essential amino acids, salt accumulation problems, possible toxic effects, etc. are all overcome. If these obstacles can be overcome, the development of halophytic agriculture in Saskatchewan might make more use of the various sources of saline waters for irrigation.

TABLE 11: Potential uses for some halophytes.

Fodder & Forage Crops

Beer Clover	Salt Bush
Sour Clover	Tall Wheatgrass
White Clover	Kochia
Persian Clover	Wild Barley
All-Scale	Bermuda Grass
Lens-Scale	Red Top
Salt Grass	Rhodes Grass
Desert Salt Grass	Marsh Grass
Tall Fescue	Alkali Sacaton
Red Fescue	Arrow Grass
Switch Grass	Bird's Foot Trefoil
Mesquite	Screw Bean
Cordgrass	

Potherbs, Medicine, Alcohol

False Camomile	Scurvy Grass
Chinese Parsley	Palms (various)
Orache	Mangroves (various)
Derris	Mesquite
Glasswort	Samphire
Pickleweed	Sea Blite
Sontonin	

Ornamental

Groundsel Bush	Chinese Parsley
Alkali Mallow	Sea Aster
Portia Tree	Brass Buttons
Sea Thrift (Pink)	Jaumea
Sea Lavender	Salt Marsh Fleabane
Statice	Bindweed
Sea Grape	Beach Morning Glory
Sea Lily	Moon Vine
Rubber Vine	Leather Fern
Wild Allemander	Silverweed
Tamarisk	

Wood, Fuel, Paper, Fibre

Sundri	New Zealand Flax
Sea Rush	Mangroves (various)
Mesquite	Cotton

Vegetables, Sugar, Fruit

Sea Lily	Beet
Sea Kale	New Zealand Spinach
Sea Radish	Date Palm
Sea Plantain	Nypa Palm
Sea Rocket	Coconut Palm

Other

Guayale - rubber
Euphorbia - hydrocarbons
Mesquite - N-fixing plant, cattle fodder, fuel wood, long taproot, protein & carbohydrate rich pods
Jojoba - seed oil (replace sperm whale oil)
Yucca - food, fibre, residues for fuel
Agave - food, sugar for alcohol, residues for fuel
Buffalo Gourd - seed production (protein, oil)
Creasote - terpenes, antioxidant N DGA
Pinyon Pine - pinyon nuts
Microalgae Biomass Production Systems
Dunaliella (algae flagellate - glycerol production)

Irrigations of halophytic forages can probably readily be conducted with waters having TDS concentrations between 3,000-10,000 mg/L. Many halophytes will tolerate even higher concentrations. As an arbitrary upper limit, assume that halophytes can be irrigated with waters up to 10,000 mg/L TDS. The utility of saline waters in Saskatchewan for irrigation of halophytic crops is summarized in Table 12.

When saline waters are examined from the perspective of irrigating salt tolerant halophytes that produce crops using waters with salt concentrations up to 10,000 mg/L, approximately 60% of the saline lakes in Saskatchewan (i.e. lakes with TDS concentrations exceeding 1,000 mg/L) are suitable for irrigation. Wastewaters and groundwaters should pose little problem to the irrigation of agricultural halophytes.

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APPENDIX I: Summary of Chemical Composition of Saline Lakes in Saskatchewan

Town	Pekakumew Spiritwood	Round Prince Albert	Big Gully Ck Maidstone	Kinderdine Maidstone	Atton Maidstone	Jackfish Battlefords
Reference	3	1	2	1	1	1
Size	---	1.3	---	.6	2.0	62
Depth	---	6.0	---	11.5	8.0	5.5
Date	06 '75	06 '39	04-07	08 '38 '67	08 '38	05 '40
Samples	1	1	4	1	1	1
pH	9.0	---	7.6	---	---	---
EC	15.0	---	---	---	---	---
TDS	16300	1307	1223	1013	1352	1237
Ca	104	47	82	21	7	22
Mg	1761	183	68.7	78.3	121.3	141
Na	1800	48.6	196	223	309	160
K	160	---	18.6	---	---	28.2
CO_3	175	7.1	0	37	68.4	45.8
HCO_3	420	231	341	517	678	387
Cl	200	2.72	63.1	9.8	31.7	13.5
SO_4	10000	741	561	346	444	581
SAR	9	1	4	5	6	3
Adj. SAR	42	2	10	13	17	8

Town	Jackfish Battlefords	Murray Battlefords	Murray Battlefords	Bitter Spiritwood	Redberry Blaine Lake	Redberry Blaine Lake
Reference	2	1	2	1	1	2
Size	---	16	---	6.5	70	---
Depth	---	8	---	16.5	24	---
Date	02-10 '67	08 '40	04-10 '67	05 '39	05 '40	02-10 '67
Samples	5	1	7	1	1	6
pH	8.7	---	8.1	---	---	8.7
EC	---	---	---	---	---	---
TDS	1932	747	1112	13981	13405	17495
Ca	30	36	65	19	72	65
Mg	214	82.6	107	1192	1590	2302
Na	286	89.7	136	2359	1547	1811
K	37.6	7.5	16.5	---	110	189
CO_3	49.8	28.0	0	241	96	94.7
HCO_3	614	243	344	8425	483	647
Cl	32.1	8.7	12.8	252	147	209
SO_4	956	361	556	8419	9086	12508
SAR	4	2	2	15	8	8
Adj. SAR	12	3	6	91	37	40

Town	Redberry Blaine Lake	Rabbit Blaine Lake	Blaine(S) Blaine Lake	Blaine(N) Nellburg	Manito Nellburg	Manito
Reference	3	3	3	3	1	2
Size	---	4.1	8.5	4.4	114	---
Depth	---	4.5	2.0	2.0	22.5	---
Date	07 '71	07 '71	05 '71	06 '75	06 '38	02-10 '67
Samples	1	1	1	1	1	6
pH	9.2	9.2	9.2	8.9	---	9.3
EC	15.6	8.8	13.0	---	---	---
TDS	19400	9700	14800	12700	20268	25098
Ca	99	28	213	280	77	98
Mg	2271	1000	1210	1046	3280	306
Na	1860	962	2130	1460	826	8005
K	178	114	163	100	---	270
CO_3	125	170	91	80	0	1063
HCO_3	551	180	288	370	1804	2659
Cl	220	133	287	200	1552	1878
SO_4	12500	5710	9450	7257	9745	12260
SAR	8	---	12	9	3	97
Adj. SAR	41	---	50	36	19	387

Town	Manito Nellburg	Little Manito Nellburg	Reflex Nellburg	Tramping Wilkie	Tramping Wilkie	Aroma Wilkie
Reference	3	3	2 & 3	2	3	3
Size	---	6.5	14.7	---	22.3	8.1
Depth	---	---	8.0	---	4.3	3.5
Date	08 '71	08 '75	06 '61	02-10 '67	08 '71	08 '75
Samples	1	1	1	3	1	1
pH	9.3	9.3	9.3	8.6	8.8	9.1
EC	25.0	3.6	---	---	10.2	41.0
TDS	23900	3300	8100	14400	8400	94200
Ca	42	10	10	32	69	200
Mg	400	76	65	268	141	9124
Na	8025	---	2900	4323	2400	12500
K	248	---	67	235	110	860
CO_3	1176	24	396	60	60	115
HCO_3	2220	298	1220	1214	691	600
Cl	1825	118	3500	494	295	3280
SO_4	12400	2450	480	9149	5080	58860
SAR	84	---	74	55	38	28
Adj. SAR	342	---	212	168	104	209

Town	Landis Biggar	Whiteshore Biggar	Wilson Biggar	Van Scoy Biggar	Opuntia Rosetown	Bad Rosetown
Reference	3	3	1	3	3	3
Size	3.3	23	2.6	6.4	15.4	12.2
Depth	---	1	6.5	1	4.3	1
Date	08 '75	08 '71	08 '38	08 '70	07 '71	06 '75
Samples	1	1	1	1	1	1
pH	9.1	8.7	---	9.6	8.7	8.5
EC	24.0	101.0	---	12.5	6.0	5.5
TDS	28200	203706	907	14100	5400	5600
Ca	408	3060	48	415	67	144
Mg	934	7384	175	1002	100	224
Na	7410	50400	16	1840	1450	1160
K	153	950	---	150	60	28
CO_3	0	94	0	58	38	7
HCO_3	542	747	359	39	586	98
Cl	798	10000	6	86	193	280
SO_4	18800	128600	259	8720	2970	3216
SAR	46	113	1	11	26	14
Adj. SAR	166	742	1	38	69	32

Town	Stockwell Outlook	Lucky Cutbank	Clearwater Kyle	Cabri Etonia
Reference	3	3	1	3
Size	5.9	24.2	.6	10.0
Depth	1.0	---	9.5	1.0
Date	06 '71	06 '75	07 '38	06 '75
Samples	1	1	1	1
pH	8.6	8.5	---	8.6
EC	10.6	---	---	---
TDS	13300	4200	781	4300
Ca	230	80	9	152
Mg	1354	438	136	151
Na	1080	750	84	1190
K	135	74	---	36
CO_3	17	19	0	38
HCO_3	222	307	541	595
Cl	140	300	20	135
SO_4	8110	2900	134	2800
SAR	6	7	2	16
Adj. SAR	24	23	4	48

	Potato	Goose & Birchbark	Goose	Birchbark	Patience	Porter
Town	Carrot River	Carrot River	Carrot River	Carrot River	Saskatoon	Saskatoon
Reference	2	2	3 & 4	3	3	
Size	---	---	12.7	2.9	10	1.9
Depth	---	---	.8	1.5	2	---
Date	08 '64	08 '64 06 '65	07 '64	08 '64	07 '71	07 '71
Samples	1	1	1	1	1	1
pH	7.6	7.6	8.6	8.2	8.8	9.0
EC	---	---	40.0	5.8	195.1	23.6
TDS	1365	8785	29400	4100	219320	25690
Ca	90	258	662	174	1880	526
Mg	43	130	438	93	2625	1690
Na	233	2622	9500	930	55200	4400
K	5	66	165	20	25200	314
CO_3	0	0	0	0	24	175
HCO_3	91	187	139	90	102	115
Cl	586	4672	16500	1990	105000	3200
SO_4	0	233	385	0	17200	13100
SAR	5	33	70	14	193	21
Adj. SAR	9	76	174	28	642	93

	Muskiki	Boucher	Buffer	Sayer	Olivier	Marie
Town	Humboldt	Wakaw	Saskatoon	Wakaw	Humboldt	Wakaw
Reference	3	3	3	3	3	3
Size	17	6.7	19.9	2.0	2.0	1.6
Depth	---	---	---	---	2.0	---
Date	07 '71	08 '75	06 '75	08 '75	08 '75	05 '71
Samples	1	1	1	1	1	1
pH	7.9	9.0	8.1	9.0	8.6	8.2
EC	91.0	6.8	7.4	17.0	12.0	29.0
TDS	370160	7500	7000	28700	13200	44800
Ca	145	160	160	380	173	426
Mg	29000	1090	511	4282	1671	3920
Na	62200	745	1100	1630	1290	5920
K	1600	103	45	201	129	256
CO_3	0	91	0	77	17	0
HCO_3	1469	132	386	500	622	528
Cl	11400	240	280	270	285	524
SO_4	237000	5800	4320	20600	8960	29200
SAR	79	5	10	5	7	20
Adj. SAR	897	18	32	31	30	110

	Arthur	Louis	Wakaw	Wakaw	Wakaw	Basin
Town	Wakaw	Humboldt	Wakaw	Wakaw	Wakaw	Wakaw
Reference	3	3	1	2	3	1
Size	2.5	1.9	13	---	---	62
Depth	---	---	9.0	---	---	10.5
Date	07 '71	08 '75	05 '39	02-10 '67	07 '71	07 '38
Samples	1	1	1	6	1	1
pH	8.6	9.0	---	8.0	8.3	---
EC	27.3	18.0	---	---	3.5	---
TDS	41500	40900	2915	3977	3700	12050
Ca	516	160	194	265	228	156
Mg	4959	6107	288	349	350	1308
Na	3345	2650	251	360	313	1448
K	395	301	---	34	32	---
CO_3	97	192	3	0	17	0
HCO_3	540	783	202	213	142	514
Cl	475	760	56	78	154	428
SO_4	26000	28400	1885	2541	2310	7430
SAR	10	7	3	3	3	8
Adj. SAR	63	50	8	10	9	35

Town	Basin Wakaw	Basin Wakaw	Middle Wakaw	Lenore Humboldt	Lenore Humboldt	Lenore Humboldt
Reference	2	3	3	1	2	3
Size	---	---	13.4	93	---	---
Depth	---	---	---	7.0	---	---
Date	02-10 '67	05 '71	08 '75	07 '38	02-10 '67	07 '71
Samples	4	1	1	1	3	1
pH	8.6	8.9	8.9	---	8.7	8.7
EC	---	16.8	23.0	---	---	6.8
TDS	19168	18700	24610	5486	7268	6900
Ca	93	252	190	46	44	63
Mg	1883	1960	1588	683	840	892
Na	2420	2200	3780	577	723	550
K	203	194	294	---	147	168
CO_3	57	0	125	0	58	130
HCO_3	643	750	590	407	582	385
Cl	625	640	880	153	196	208
SO_4	11359	12000	13120	3316	4313	4160
SAR	12	10	20	5	5	4
Adj. SAR	55	49	88	16	20	15

Town	Haughton Humboldt	Deadmoose Humboldt	Waldsea Humboldt	Humboldt Humboldt	Humboldt Humboldt	Charron Nalcam
Reference	3	3	3	1	3	1
Size	22.1	---	---	4.4	---	6.5
Depth	---	---	---	5.5	---	7.0
Date	08 '75	07 '71	07 '71	07 '40	07 '71	07 '38
Samples	1	1	1	1	1	1
pH	8.9	8.5	8.5	---	8.7	---
EC	26.0	28.0	24.7	---	3.9	---
TDS	26500	27800	25400	7828	4300	7080
Ca	208	268	316	121	145	92
Mg	1771	1592	2724	1018	517	807
Na	5040	5390	3125	411	250	812
K	129	324	290	180	94	---
CO_3	67	122	53	38	31	0
HCO_3	588	429	254	296	268	464
Cl	2320	6000	3850	65	88	224
SO_4	14570	11000	12600	5009	2620	4300
SAR	25	28	12	3	2	6
Adj. SAR	110	118	60	10	7	22

Town	Edward's Nalcam	Ponass Nalcam	Little Manito Watrous	Little Manito Watrous	Little Manito Watrous	Big Quill Quill Lake
Reference	1	1	1	2	3	1
Size	2	48	21	---	6.5	420
Depth	4	1	3.5	---	---	6
Date	07 '38	07 '38	07 '40	02-10 '67	06 '71	07 '39
Samples	1	1	1	3	1	1
pH	---	---	---	8.7	8.8	---
EC	---	---	---	---	72.5	---
TDS	894	1025	120300	197030	95900	30022
Ca	51	70	514	623	497	117
Mg	111	101	11160	26821	9518	2467
Na	49	102	17950	24342	12300	4511
K	---	---	1017	2354	890	---
CO_3	0	0	236	324	209	89
HCO_3	226	227	554	2000	776	430
Cl	3	25	25295	52565	18000	2097
SO_4	462	532	51720	87665	39600	16120
SAR	1	2	102	32	27	19
Adj. SAR	2	4	371	385	209	93

Town	Big Quill Quill Lake	Big Quill Quill Lake	Little Quill Wadena	Little Quill Wadena	Little Quill Wadena	Fishing Wadena
Reference	2	3	1	2	3	1
Size	---	---	182	---	---	36
Depth	---	---	1.5	---	---	10.5
Date	02-10 '67	07 '71	07 '39	02-10 '67	07 '75	07 '38
Samples	3	1	1	3	1	1
pH	8.2	8.7	---	8.3	8.7	---
EC	---	37.5	---	---	7.5	---
TDS	50880	53200	21387	5832	5200	3183
Ca	199	382	131	178	56	84
Mg	4700	4482	1820	477	622	369
Na	9704	8050	3115	930	515	279
K	616	575	---	112	58	---
CO_3	0	133	71	0	10	0
HCO_3	845	793	382	575	100	280
Cl	3857	3510	1435	453	400	52
SO_4	32015	30200	11650	3332	3100	1891
SAR	28	25	15	8	4	3
Adj. SAR	166	152	68	28	12	9

Town	Fishing Wadena	Margo Wadena	Good Spirit Yorkton	Good Spirit Yorkton
Reference	3	1	1	2
Size	---	2.6	44	--
Depth	---	3.2	4	---
Date	08 '71	07 '38	07 '38	02-10 '67
Samples	1	1	1	3
pH	8.7	---	---	7.7
EC	4.4	---	---	---
TDS	4300	1434	868	1003
Ca	113	87	41	52
Mg	496	166	126	148
Na	390	213	39	33
K	76	---	---	25
CO_3	53	0	0	0
HCO_3	281	202	236	341
Cl	66	7	7	11
SO_4	2540	831	420	515
SAR	4	3	1	1
Adj. SAR	12	8	2	1

Town	Bitter Maple Creek	Golden Prairie Maple Creek	Big Stick Maple Creek	Crane Maple Creek	Antelope Gull Lake	Antelope Gull Lake
Reference	2 & 3	3	2	1 & 3	1	3
Size	17	.32	10.7	26.5	16	13.6
Depth	<1	2.0	---	---	8.2	8.2
Date	10 '66	07 '71	07 '71	10 '66	08 '38	07 '71
Samples	1	1	1	1	1	1
pH	7.9	9.8	9.0	8.6	---	9.0
EC	---	9.0	7.6	---	---	8.4
TDS	233970	8100	6500	2400	13640	8900
Ca	550	65	78	11	22	67
Mg	29700	536	344	188	1132	642
Na	18200	1630	1400	506	2328	1360
K	2720	90	95	107	---	123
CO_3	0	209	74	126	0	85
HCO_3	1840	129	608	1527	717	577
Cl	44500	780	684	78	325	239
SO_4	95510	4350	3240	466	801	4840
SAR	23	15	15	8	15	11
Adj. SAR	281	49	49	27	59	41

Town	Reed Herbert	Chaplin West Chaplin	Chaplin East Chaplin	Chaplin South Chaplin	Midskogen Chaplin	Old Wives Moose Jaw
Reference	3	3	3	3	3	2
Size	20	19	14	27	16.7	---
Depth	---	<1	<1	2	---	---
Date	06 '75	07 '71	06 '71	06 '71	08 '71	02-10 '67
Samples	1	1	1	1	1	3
pH	---	9.0	9.2	9.0	9.1	8.6
EC	6.0	120.0	71.4	7.5	11.5	---
TDS	4200	221500	140860	6410	10140	17095
Ca	24	1530	350	49	78	33
Mg	214	5048	1554	238	366	638
Na	953	59600	29600	1590	2770	4231
K	55	2200	700	65	124	133
CO_3	86	828	552	108	312	200
HCO_3	388	1927	1891	817	634	953
Cl	105	11200	3120	270	420	361
SO_4	2370	132000	65000	3260	6190	9774
SAR	14	166	151	21	---	35
Adj. SAR	39	1012	648	65	---	130

Town	Old Wives Moose Jaw	Lake of Rivers Assiniboia	Twelve Mile Assiniboia	Willowbunch Willowbunch	Fife Coronach	Fife Coronach
Reference	3	3	3	2 & 3	2	3
Size	296.2	36.7	2.6	38.2	---	30.2
Depth	1.0	2.0	1.0	1.0	---	3.7
Date	08 '71	08 '64	08 '71	10 '66	02-10 '67	08 '71
Samples	1	1	1	1	3	1
pH	9.5	9.6	9.6	9.3	9.1	9.3
EC	5.0	4.5	5.2	---	---	3.0
TDS	4600	3800	4400	31500	2975	2600
Ca	102	47	47	90	20	64
Mg	192	53	61	300	110	68
Na	1110	1080	1360	9930	852	680
K	60	53	80	250	61	58
CO_3	216	60	516	900	179	324
HCO_3	505	8130	1318	2515	1172	708
Cl	110	304	91	2247	34	24
SO_4	2500	1455	1545	15570	1148	895
SAR	15	26	31	113	17	14
Adj. SAR	47	69	100	430	52	43

Town	Big Muddy Coronach	West Coteau Lake Alma	Lonetree Lake Alma	Last Mountain Regina	Last Mountain Regina Beach	Last Mountain Etter's Beach
Reference	3	3	3	1	2	2
Size	38.9	9.1	1.4	210	---	---
Depth	---	1.0	---	24	---	---
Date	05 '71	05 '71	05 '71	07 '40	02-10 '67	02-10 '67
Samples	1	1	1	1	6	5
pH	8.8	8.9	8.7	---	8.4	8.3
EC	3.4	42.9	8.6	---	---	---
TDS	3200	43800	10770	2549	2120	2115
Ca	48	213	339	44	59	55
Mg	36	721	1052	167	125	129
Na	850	13000	885	527	413	410
K	25	210	160	17	37	36
CO_3	0	96	67	34	7	0
HCO_3	825	756	249	364	389	399
Cl	182	1165	102	178	157	153
SO_4	1270	29800	6350	1302	1049	1055
SAR	23	96	---	8	7	7
Adj. SAR	58	308	---	22	19	19

Town	Arm River Bethune	Pasqua Ft. Qu'-Appelle	Pasqua Ft. Qu'-Appelle	Echo Ft. Qu'-Appelle	Echo Ft. Qu'-Appelle	Mission Ft. Qu'-Appelle
Reference	2	1	2	1	2	2
Size	---	15	---	10	---	---
Depth	---	15	---	17	---	---
Date	04-07 '67	06 '38	02-10 '67	07 '40	02-10 '67	02-10 '67
Samples	4	1	3	1	3	3
pH	8.0	---	8.3	---	8.2	8.0
EC	---	---	---	---	---	---
TDS	1314	955	1488	1294	1673	1937
Ca	76	58	97	60	88	77
Mg	85	55	77	71	100	101
Na	151	184	275	252	302	330
K	16.5	---	22.7	22.4	24.7	26.3
CO_3	0	0	4.7	16.0	6.0	3.3
HCO_3	307	269	441	274	410	409
Cl	26	66	138	105	142	140
SO_4	587	426	623	594	756	825
SAR	3	4	5	5	5	6
Adj. SAR	7	10	14	13	14	16

Town	Katepwa Ft. Qu'-Appelle	Katepwa Ft. Qu'-Appelle	Crooked Broadview	Crooked Broadview	Round Broadview	Round Broadview
Reference	1	2	1	2	1	2
Size	13	---	15	---	10	---
Depth	20	---	13	---	11.5	---
Date	06 '38	02-10 '67	06 '38	02-10 '67	06 '38	02-10 '67
Samples	1	6	1	5	1	6
pH	---	8.3	---	8.2	---	8.2
EC	---	---	---	---	---	---
TDS	973	1529	1008	1352	887	1157
Ca	50	70	50	65	53	66
Mg	56.6	90.3	57.8	77.7	53.5	69
Na	186	289	199	251	169	200
K	---	25.7	---	21.3	---	18.3
CO_3	0	10.2	0	0	0	47
HCO_3	237	363	243	353	245	318
Cl	67.8	117	71.5	83.3	58.5	72.5
SO_4	421	714	452	628	395	529
SAR	4	5	5	5	4	4
Adj. SAR	10	14	10	13	9	11

Town	Carlyle Carlyle	Carlyle Carlyle	Kenosee Carlyle	Kenosee Carlyle
Reference	1	2	1	2
Size	10	--	8	--
Depth	15	---	7.5	---
Date	06 '39	02-10 '67	06 '38	02-10 '67
Samples	1	6	1	6
pH	---	8.8	---	8.7
EC	---	---	---	---
TDS	1341	1842	1186	1513
Ca	34.7	15	41.8	28
Mg	211	303	184	239
Na	83.5	76	37.4	51.2
K	---	43.8	---	44.7
CO_3	0	67	0	32.5
HCO_3	411	548	309	429
Cl	18.8	25.1	18	16
SO_4	628	904	587	779
SAR	1	1	1	1
Adj. SAR	3	3	2	2

References: 1. Rawson and Moore 1944; 2. Rutherford 1970; 3. Hammer 1978.

EVALUATING SALINE WATERS IN A PLAINS ENVIRONMENT

Edited by Don T. Waite

Brackish and saline waters are common in the Central Plains region. They serve many varied and often conflicting uses. The purpose of this publication is to evaluate the uses of these waters, to highlight the conflicting demands and in this way to assist planners in preserving the resource.

The six papers published here were presented at the fourth biennial Plains Aquatic Research Conference, sponsored jointly by the Water Studies Institute and the Canadian Plains Research Center. Included are *Saline Lakes: Their Distribution and Characteristics* by U.T. Hammer; *Saline Lake Management: A Review of Concepts* by M.D. Scott and S.A. Scott; *Industrial Experience with Prairie Waters* by W.H. Gardiner; *Recreation Potential of Saline Lakes in Saskatchewan* by A.G. Appleby and R. Green; *Fish in Saskatchewan Endorheic Systems and Saline Waters* by F.M. Atton; and *Saline Waters: Agricultural Uses* by D.A. Cameron.

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